

Future Directions for Space Transportation and Propulsion at NASA

5th International Symposium on Liquid Space Propulsion
Long-Life Combustion Devices Technology
Chattanooga, TN
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Robert L. Sackheim
Assistant Director and
Chief Engineer for Propulsion
NASA Marshall Space Flight Center

The NASA Mission:

To understand and protect our home planet,

To explore the universe and search for life,

To inspire the next generation of explorers . . .

. . . as only NASA can.

Space Is Critical to the World

The New International "Ocean"



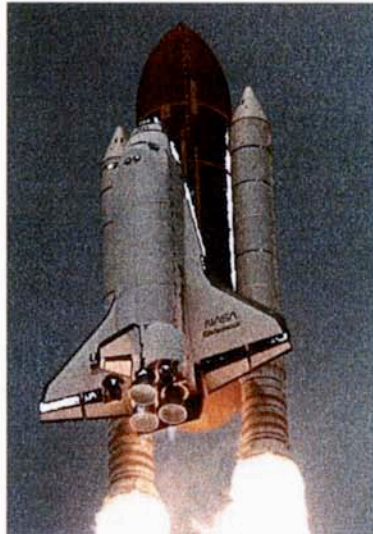
- ◆ Scientific Discovery
 - The Search for Life Beyond Earth
 - Understanding our Planet
 - Understanding our Universe
 - Exploration of the Planets and Beyond
- ◆ The Ultimate High Ground for National Security
 - Intelligence, Communications, Rapid Response, GPS . . . World Wide
- ◆ "Space-Based" Commerce
 - Communications and Earth Observing

Yet it Remains the Last, Largely Untapped Frontier

MSFC's Heritage – Complex Programs Requiring a Strong Systems Engineering Focus



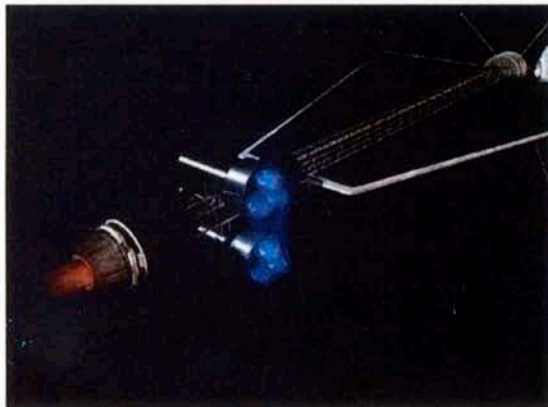
SATURN V



SHUTTLE



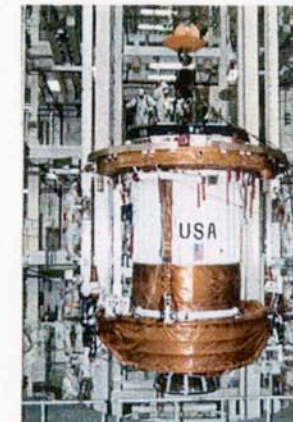
SPACE STATION



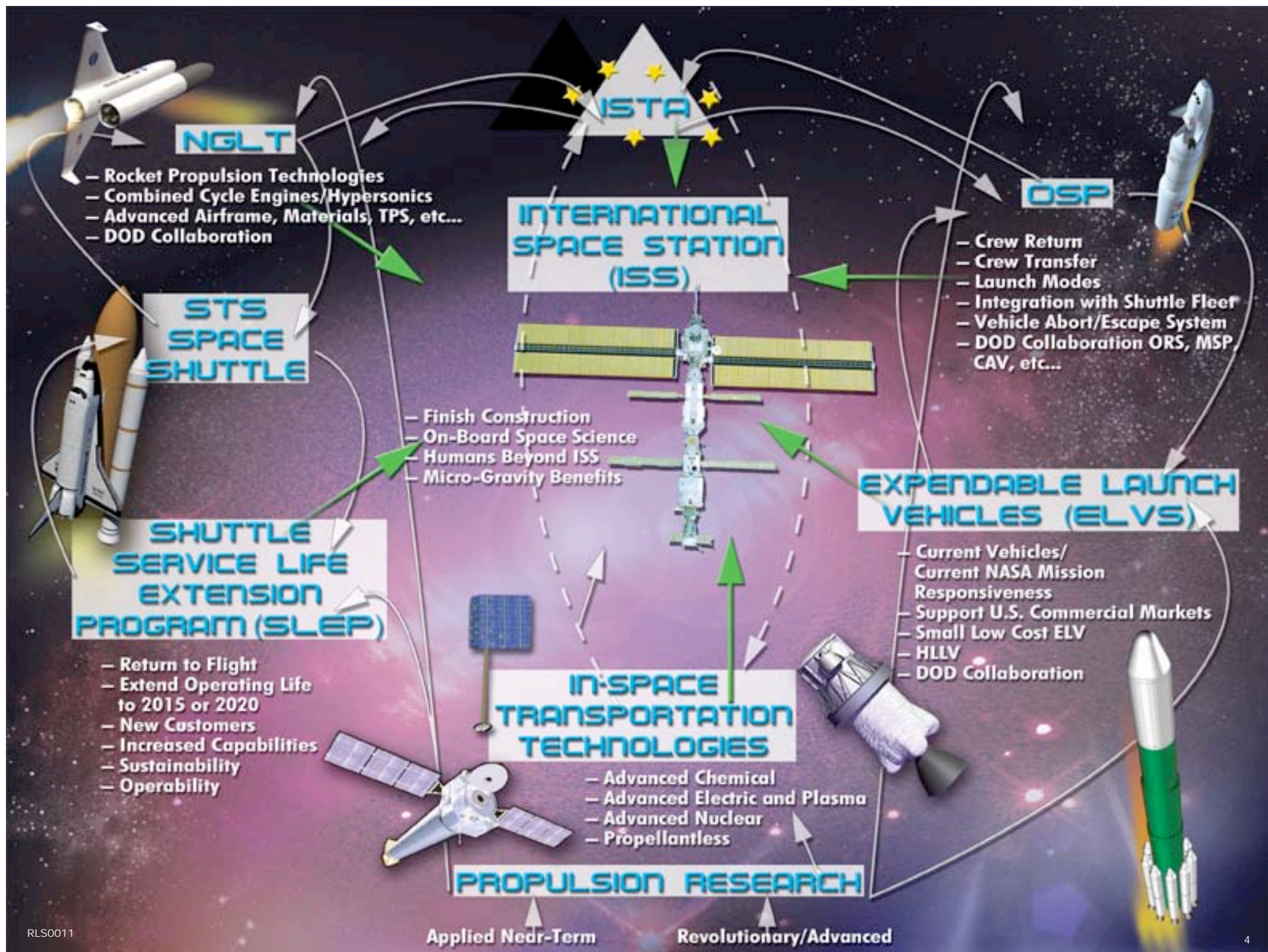
NEP VEHICLE DESIGN

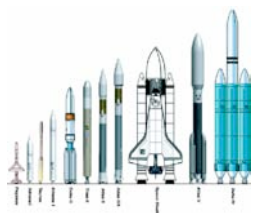


CHANDRA

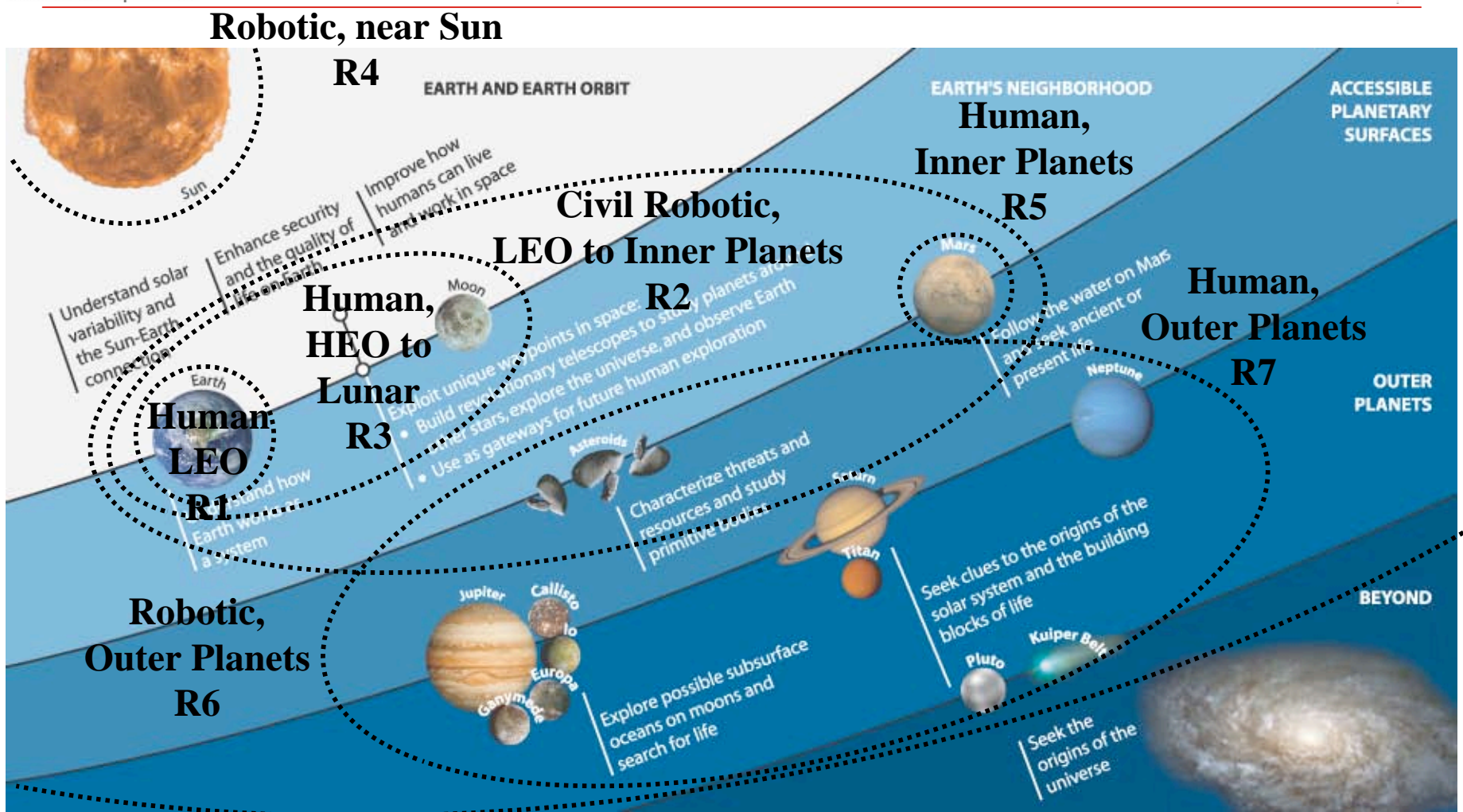


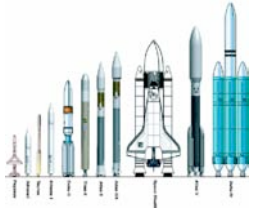
INERTIAL UPPER STAGE





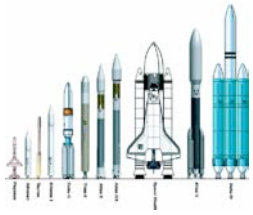
Stepping Stones Overlay on Space Transportation Regimes





Regime Descriptors and Needs

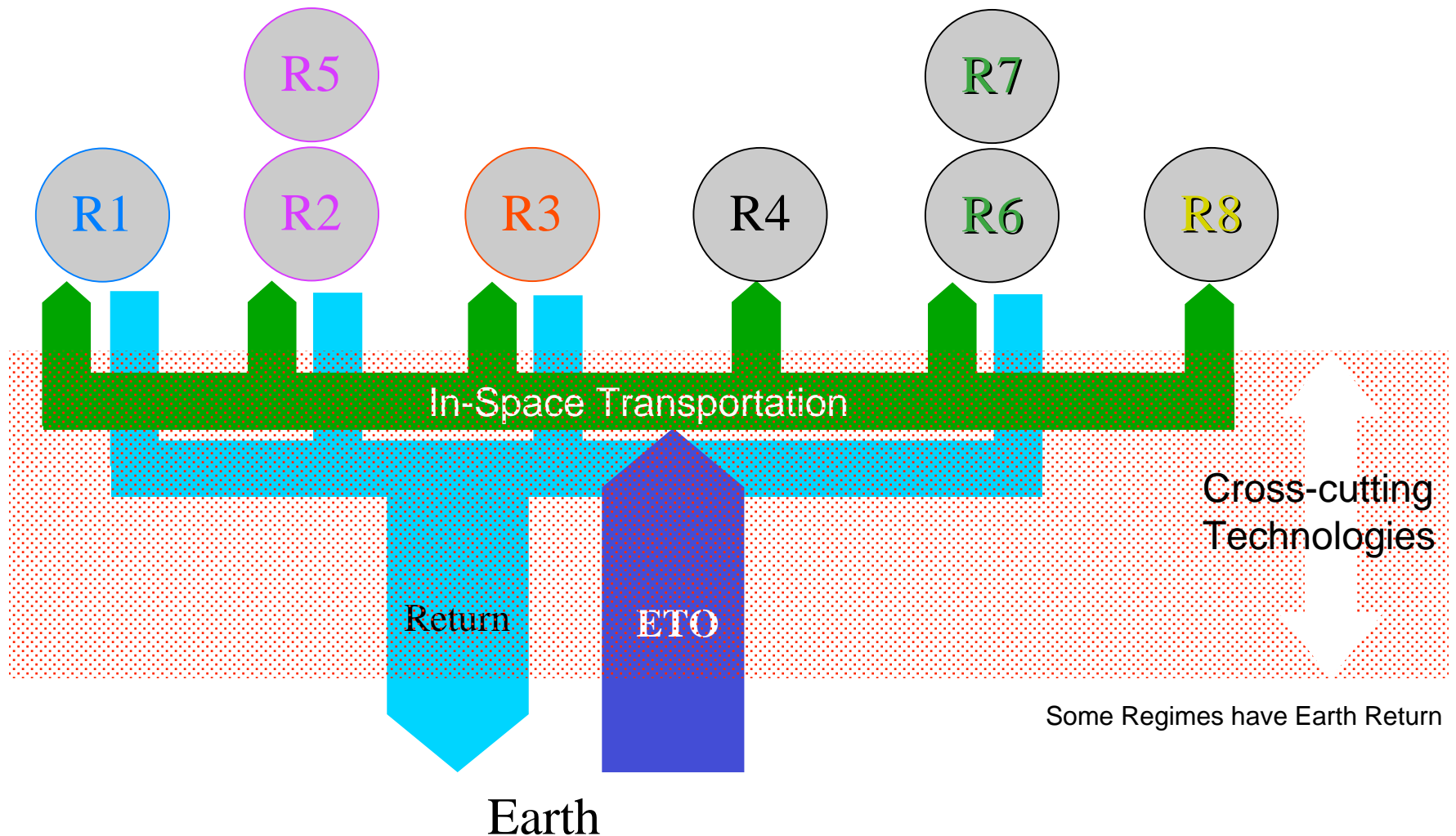
R1	Human Earth Orbit	ISS and other near-Earth missions	Frequent access; safety; medium cargo; reduced cost
R2	Robotic LEO to near planets	Earth & space observation; planetary science; sample return	State of art mainly OK; reduced cost; higher reliability; landing & ascent systems
R3	Human HEO and lunar	Missions in cislunar space & lunar surface and basing	Medium space transfer/cargo, landing, safety, reduced cost
R4	Robotic near-Sun	Mercury, solar probes, solar polar	High delta V, reduced cost, ETO state of art OK
R5	Human near planets	Mars and Mars surface, asteroids, exploration and basing	Increased lift to LEO, heavy space transfer, short trip time, reduced cost, safety, artificial g
R6	Robotic outer planets	Orbiters, probes, landers, sample return	Reduced trip time, high/very high delta V, nuclear electric power, reduced cost, ETO state of art OK
R7	Human outer planets	To Jupiter and Saturn moons, landing, return	Fast trips, very high delta V, heavy space transfer, nuclear power
R8	Robotic beyond planetary system	Kuiper belt, Oort cloud, interstellar medium	Very/extremely high delta V, nuclear electric power

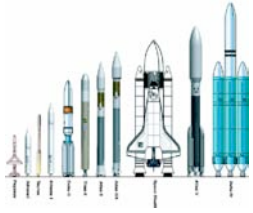


End-to-End Regimes Capture Mission Requirements

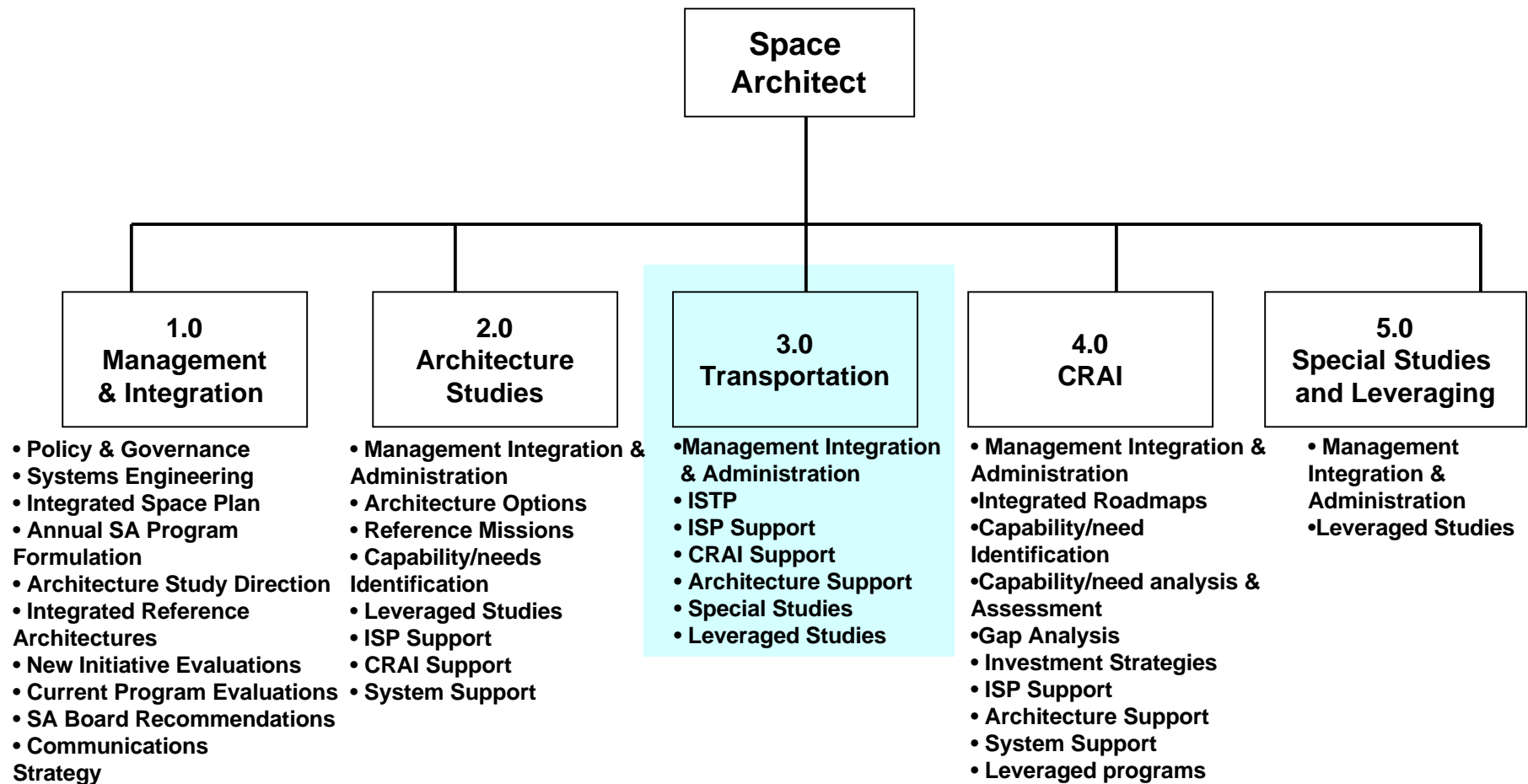


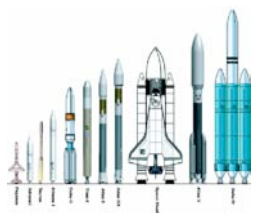
Equal emphasis over all Regimes favors NASA-Wide Propulsion Requirements



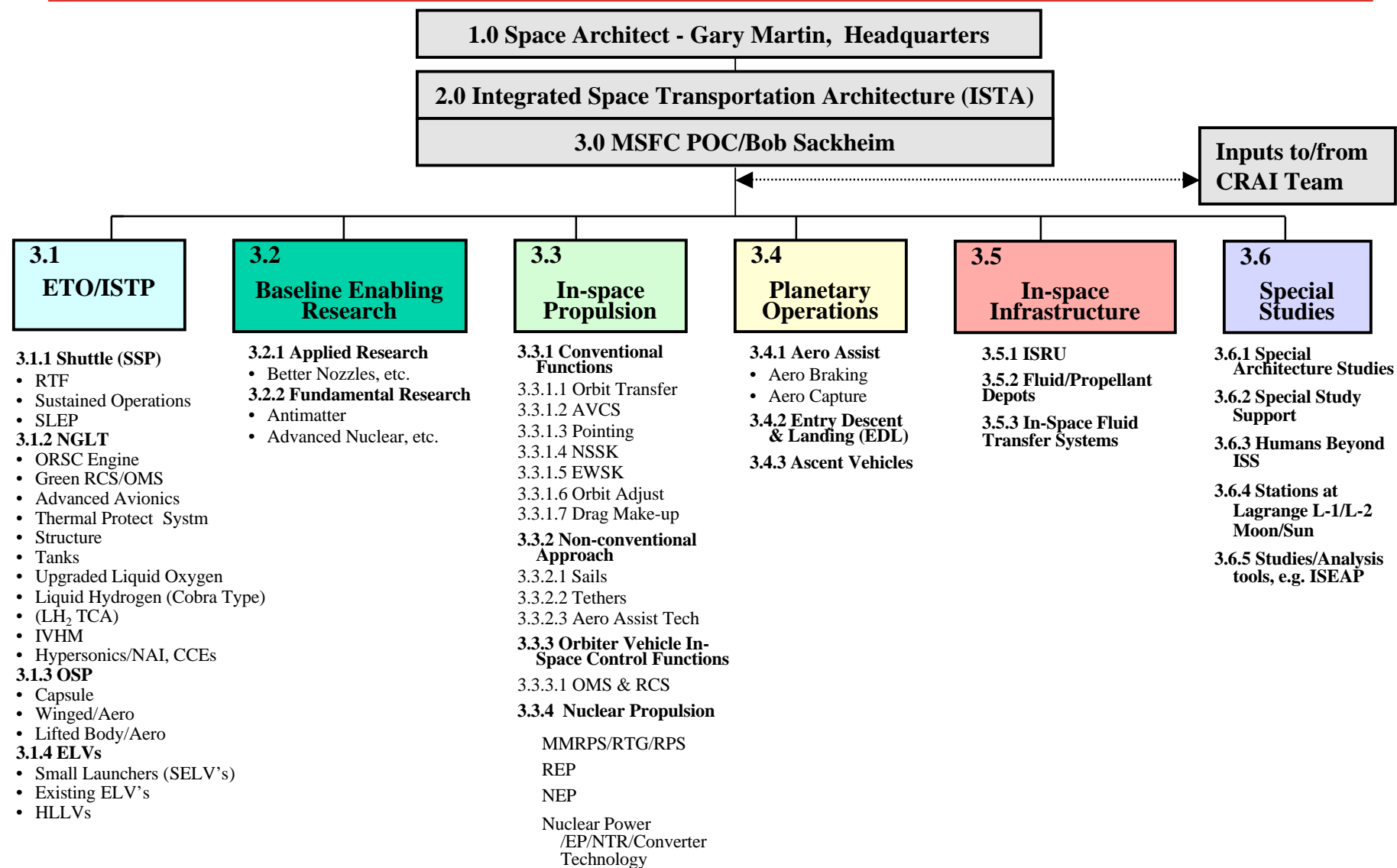


Work Breakdown Structure





Integrated Space Transportation Architecture Inputs to the Space Architecture Work Breakdown Structure Format

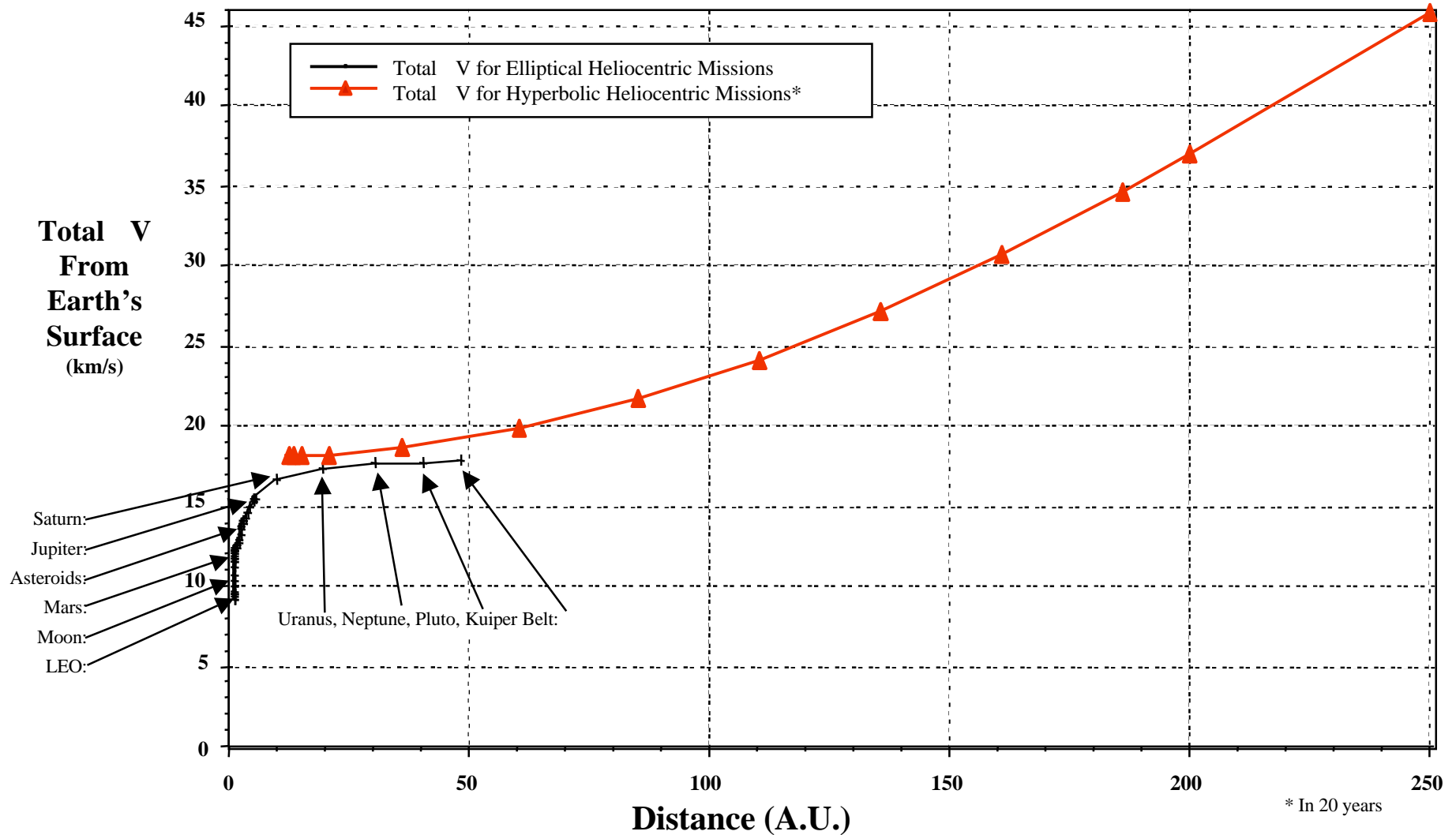


The Physics Problem

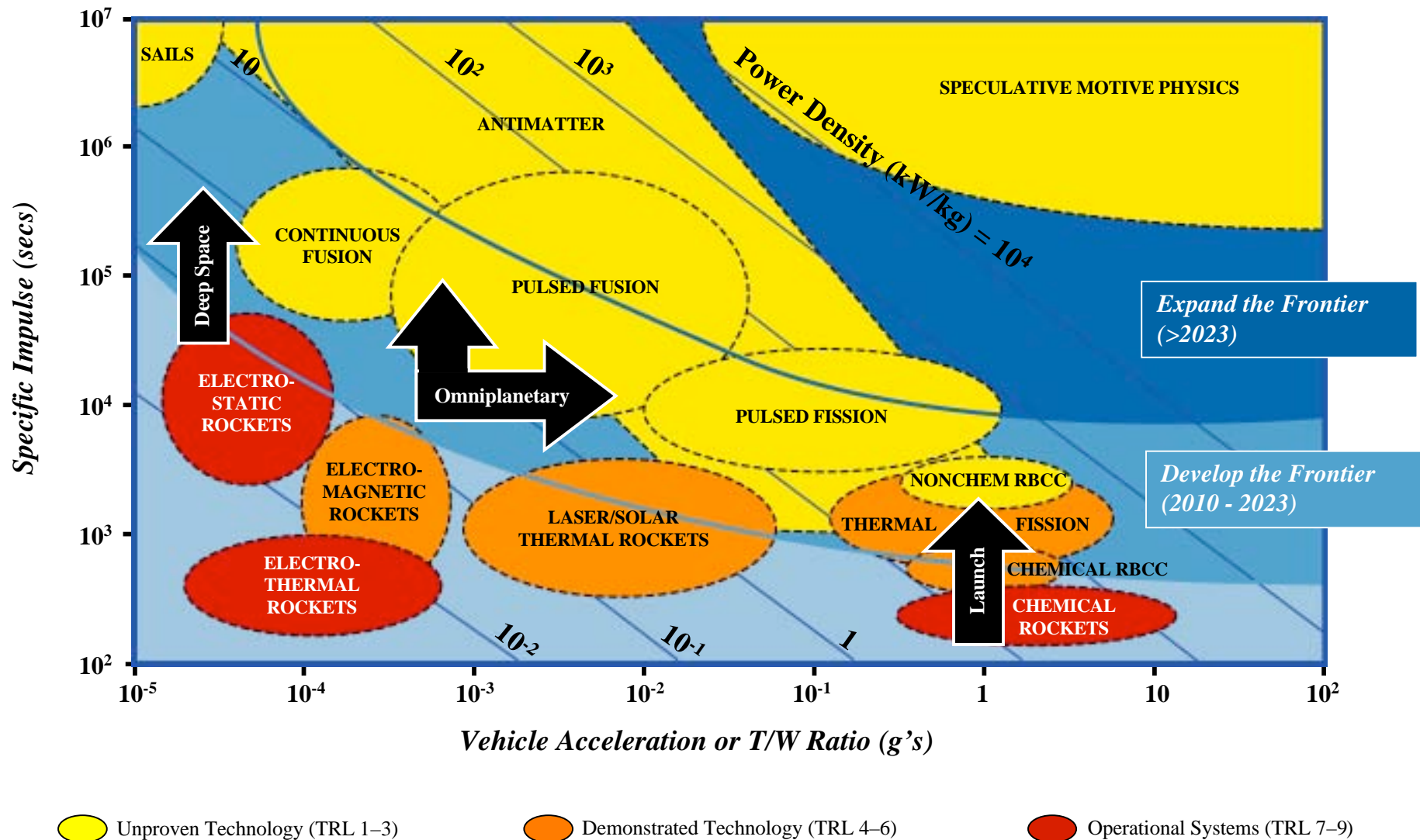


Energy Comparison for Various Distances

Single Burn Delta V From LEO, ETO $V = 9.3$ km/s



New Propulsion Technologies are Needed to Meet NASA's Most Ambitious Goals



NASA's New Integrated Space Transportation Plan (ISTP)

Space Shuttle Life Extension Upgrades

Orbital Space Plane (OSP)

- ISS Crew Rescue by 2010
- ISS Crew Transfer by 2012



Next Generation Launch Technology (NGLT)

- Enabling Future National Launch Capabilities

Enabling Near and Long Term Improvements in U.S. Launch



Imagine the Possibilities....



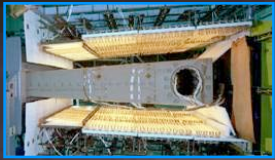
- Significant Expansion in Robotic Probes Going Throughout the Solar System and Beyond
- Humans Exploring Space Beyond Low Earth Orbit
- Space Solar Power Systems Supplying Cheap Electricity Around the Globe
- Daily Tours To and From Space
- Industrial Space Platforms Developing New Materials and Medicines

*A Primary Limitation is
Safe, Reliable and Affordable Space Launch*

High Leverage, Cross-Cutting Technologies for Any Future Launch System



Cutting Edge Hypersonics Technologies for Future, Aircraft-like Operations



Long Life, High
Temperature
Structures and
Materials



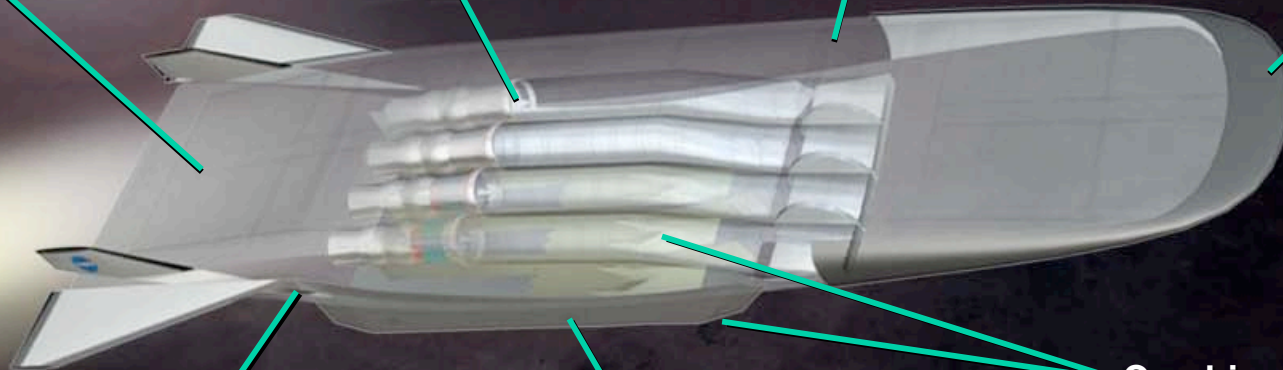
Mach 4 Turbine
Engines



Highly Integrated
Airframe Systems



Ultra High-Temp
Leading Edges



Integrated
Rockets



Ram / Scramjets



Combined Cycle
Propulsion
Systems



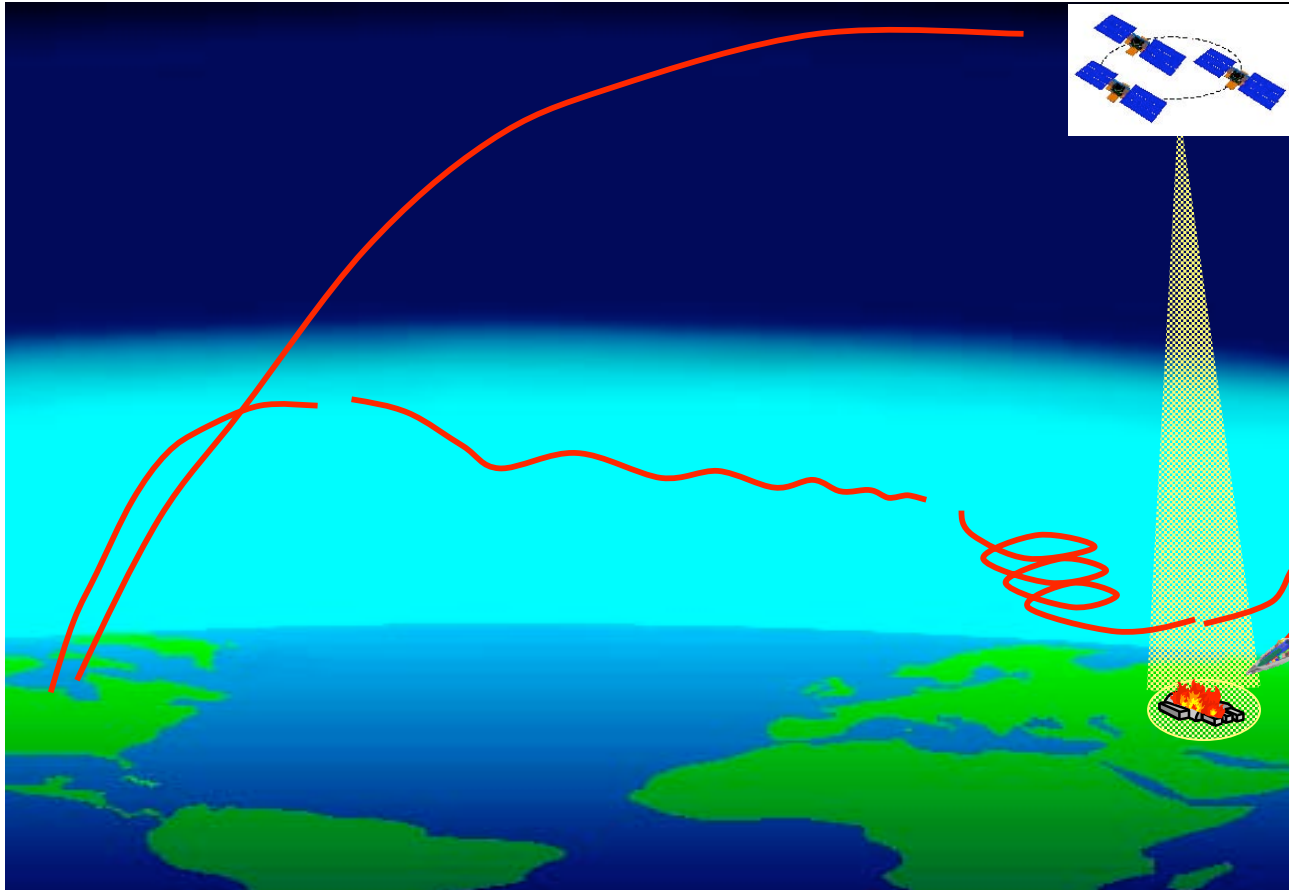
DARPA/USAF Small Launcher Initiative



- DARPA and the Air Force have established a joint program
- DARPA has overall program management primacy
- The program is called FALCON (Force Application Launch from CONUS)
- FALCON RFP released on July 29, 2003
- The FALCON SLV initiative has some similarities to MSFC's original Bantam Project



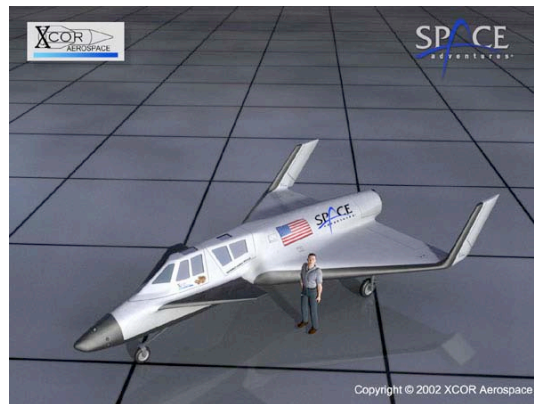
FALCON





FALCON

Many respondents to
FALCON RFI (1/30/2003)





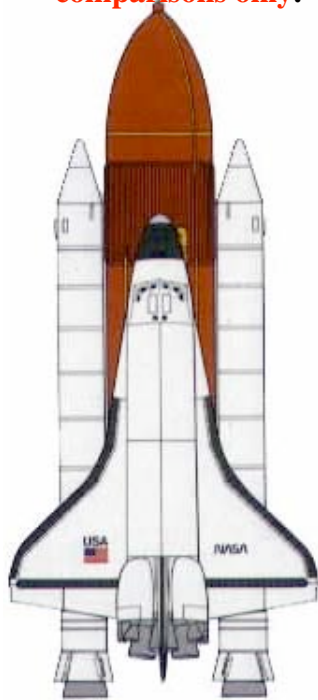
Why Will It Work This Time?

- **Simplicity of Design**
 - Some simple designs are inherently more reliable and lower cost than others
 - See RLS papers for last 20 years
 - NASA and DOD have really shown zero interest in inherently low costs
- **Trade Design Margin Against Performance and Weight**
 - Nontraditional aerospace design philosophy
 - Greater design margins enhance reliability
 - Very high Thrust-to-Weight is not that critical for low cost, vertical launch
 - Lower Thrust-to-Weight is more reliable (but vehicle T/W >1.1 @ liftoff)
- **Trade Design Margin Against Redundant Systems**
 - Redundancy adds complexity and cost
- **Use Rack and Stack Design Approach to Achieve Component Commonality**
 - Commonality enables simplicity and lowers cost
 - Commonality enhances reliability
 - Provides evolutionary design approach for heavy lift using flight-proven building blocks
- **Use Commercial (non-aerospace) Processes and Components As Much as Possible**
 - Leverage commercial industry's production rate
 - Commercial components are inherently higher margin; not optimized for performance
 - Commercial hardware is dramatically lower cost than comparable aerospace hardware

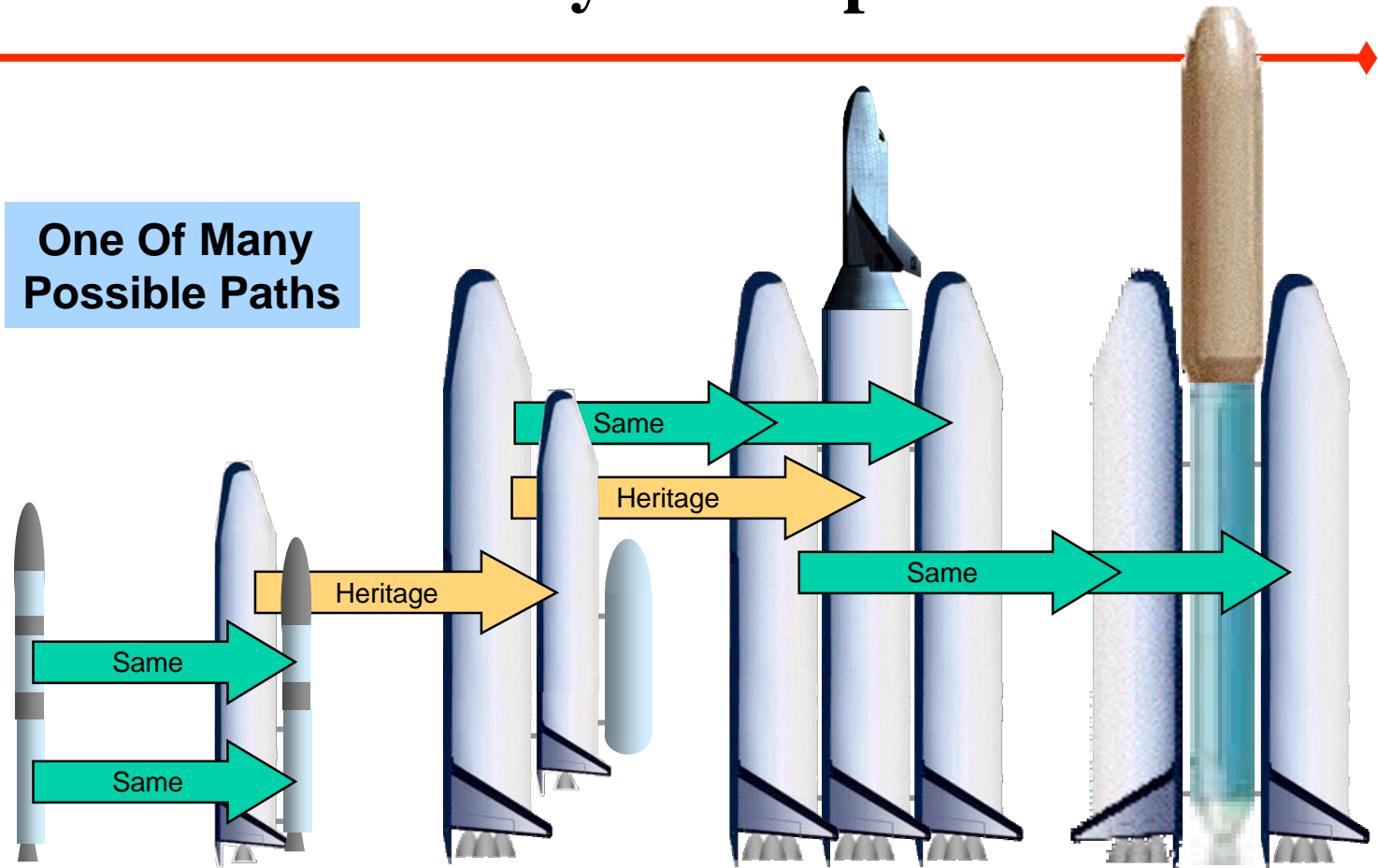


Notional Evolutionary Development Path

Shuttle depicted for size comparisons only.



One Of Many Possible Paths



Stage 1 Engine
Stage 2 Engine
Stage 3 Engine

FALCON

New RP
New RP
New RP

Spiral 1

2 SSME
FALCON Stage 2
FALCON Stage 3

Spiral 2

New LH Engine (4)
Spiral 1 Stage 1
--

Spiral 3

Same as Spiral 2
Same as Stage 1
--

Spiral 4

Same as Spiral 2
EELV Core
EELV US

Technology Application to Shuttle Upgrades (Initial NGLT Assessment)

External Tank

- Self Reacting Friction Stir Welding
- Advanced Cryoinsulation

Booster

- LOx/RP liquid booster replacement (1+Mlb Prototype Engine)

Airframe Structure

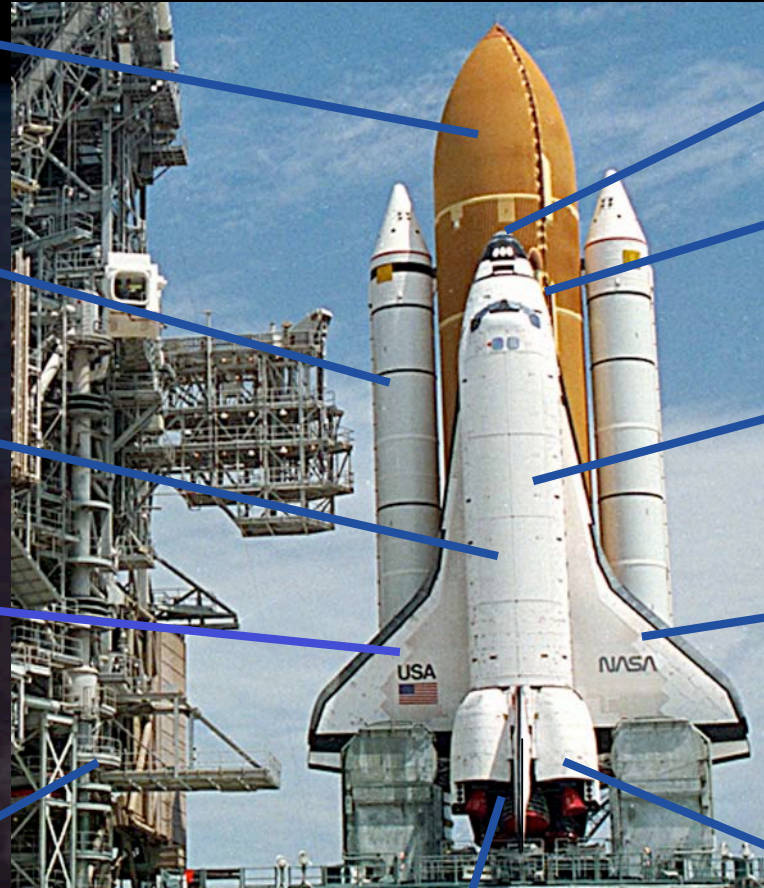
- Ceramic Matrix Composite Control Surfaces
- Structural Health Monitoring Sensors

Thermal Protection Systems

- Light Weight, Intelligent Micrometeoroid Resistant Ceramic TPS
- Durable, Conformal Reusable Insulation
- Long Life, Durable Thermal Seals
- Rapid Waterproofing

Ground Operations

- Space Based Telemetry and Range Safety
- Silent Sentry/Passive Coherent Location (Advanced Range Technology)
- Range Architecture Development
- Advanced Umbilical Development
- Improved Propellant Management
- Densified Propellants
- Advanced Checkout Control and Maintenance System
- Launch Acoustic Environment Prediction



RCS/OMS

- LOx/Ethanol Dual-Thrust Level RCS Thrusters

IVHM System Integration

- Advanced Systems/Subsystems Diagnostic Algorithms
- IVHM/Flight Operations Integration

Subsystems

- High Horsepower, Electrically Driven Actuators
- PEM Fuel Cells
- Nontoxic Turbine Power Unit

Aero & GN&C Tools

- Separation and Abort Scenarios
- Reentry Heating Environments
- Localized Heating
- Integrated Development and Operations System
- Integrated Aerothermal/TPS Sizing

Aft Compartment

- Oxygen and Hydrogen Leak Detectors

SSME

- IPD Channel Wall Nozzle
- Advanced Turbomachinery
- GRCop-84 Main Combustion Chamber Liner
- Advanced Engine Health Management

Technology Application to Expendable Launch Upgrades (*Initial NGLT Assessment*)

Tanks

- Self Reacting Friction Stir Welding
- Advanced Cryoinsulation

Structures

- Structural Health Monitoring Sensors
- Lightweight metal matrix and polymer matrix composite structures

Ground Operations

- Space Based Telemetry and Range Safety
- Silent Sentry/Passive Coherent Location (Advanced Range Technology)
- Range Architecture Development
- Advanced Umbilical Development
- Improved Propellant Management
- Densified Propellants
- Advanced Checkout Control and Maintenance System
- Launch Acoustic Environment Prediction



IVHM System Integration

- Advanced Systems/Subsystems Diagnostic Algorithms
- IVHM/Flight Operations Integration

Subsystems

- High Horsepower, Electrically Driven Actuators
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Aero & GN&C Tools

- Separation and Abort Scenarios
- Reentry Heating Environments
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- Integrated Development and Operations System

Aft Compartment

- Oxygen and Hydrogen Leak Detectors

Replacement RP Engine

- LOx/RP liquid booster replacement (1+MIb Prototype Engine)

LH₂ Engine Upgrades

- IPD Channel Wall Nozzle
- Advanced Turbomachinery
- GRCop-84 Main Combustion Chamber Liner
- Advanced Engine Health Management

Enabling "Firsts" in Space Launch Technology

Booster Engine Prototype



- Highly reliable hydrocarbon fueled rocket booster engine
- High reliability, long life hydrogen rocket engines

Auxiliary Propulsion



- Non-toxic propellants for orbital propulsion
- Airframes capable of containing cryogenic propellants and reentering the Earth's atmosphere
- Durable high temperature thermal protection systems
- An intelligent, autonomous "all electric" launch system

Vehicle Research and Technology



Propulsion Research & Technology

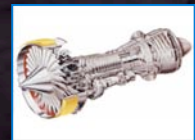


X-43A and C



- Long life, lightweight high temperature materials, seals and components
- 1st controlled flight of a vehicle powered by a scramjet from Mach 5 - 7 and 10

Revolutionary Turbine Accelerator



- Lightweight, long life jet engines capable of flight at Mach 4

**Think of What We Have Accomplished
in the 100 years Since the Wright
Brothers 1st Flight**





In-Space Focused Scope

Orbital Transfer Vehicles

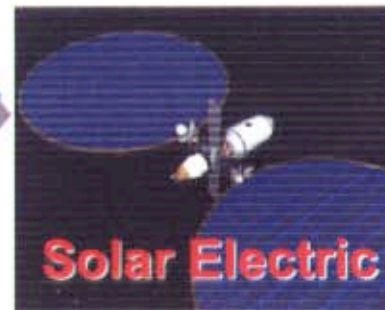


Reusable
Upperstage



Tethers

Interplanetary Transfer Stages



Solar Electric

Planetary Capture



Aerocapture

Ascent/Descent Stages

Sample
return



In-Situ Prop/
Ascent Chem
Prop Stage

Enabling New Scientific Discoveries

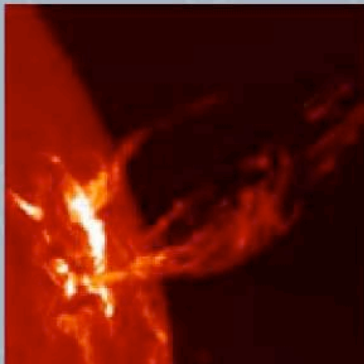
Solar System Exploration



◆ Planetary Exploration Examples:

- Orbiters
- Landers
- Sample Return

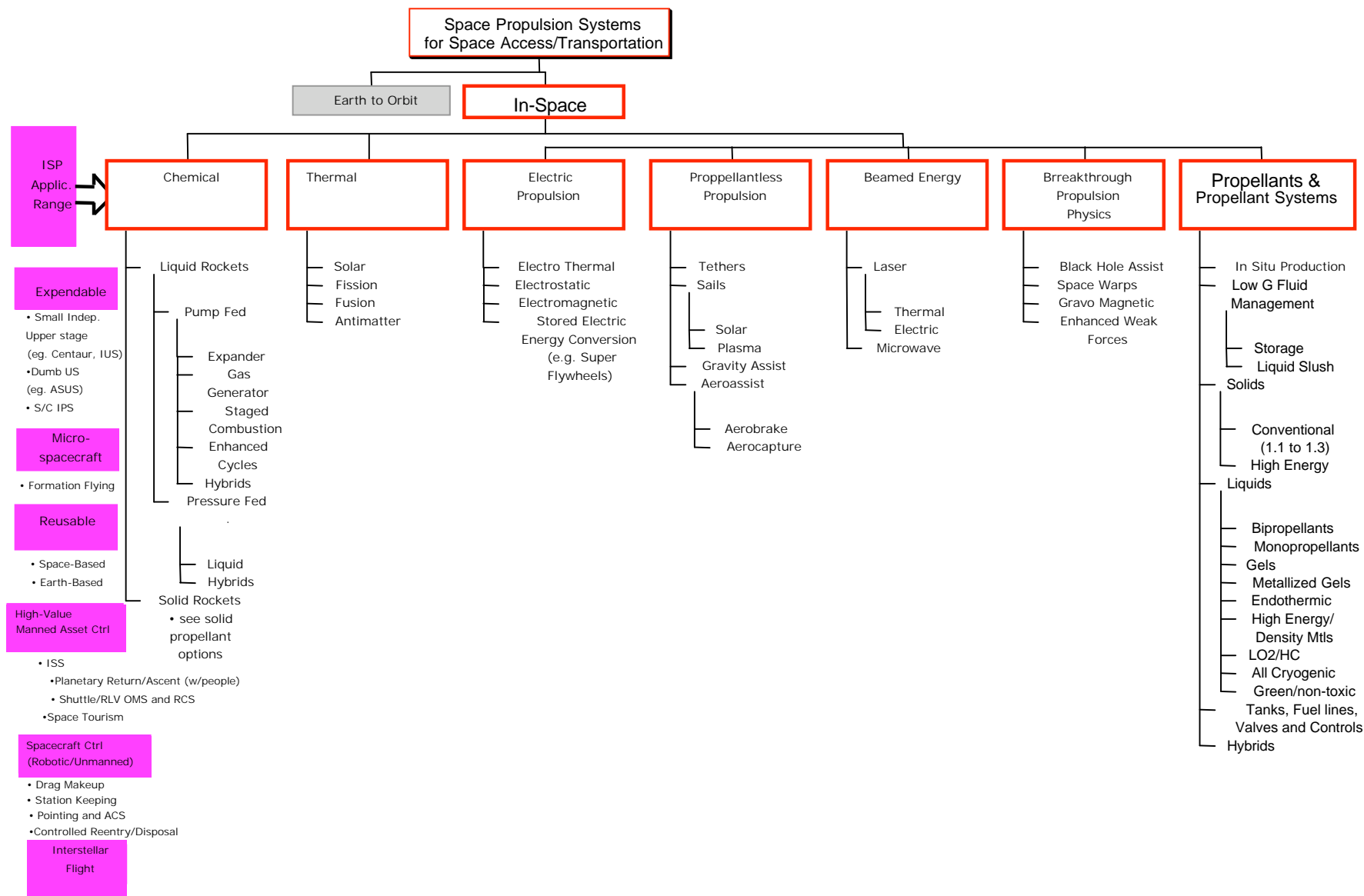
Sun Earth Connection



◆ Solar Science Examples (inc. Solar Sails):

- LaGrange Missions
- Orbiters
- Pole Sitters

In-Space Propulsion Systems



Missions Often Characterized by "Delta V"

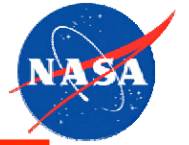


Typical Mission Examples

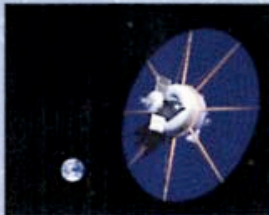
	ΔV Required KM/SEC
• 10 Year GEO Stationkeeping	~0.5
• LEO to GEO (0.3 days)	~4
• LEO to GEO (250 days)	~6
• Titan Orbiter (1way)	~11
• Neptune SR (NEP)	~85
• LEO to Alpha Centauri	30000.0

Far Away Places Truly Stress the Bounds of Propulsion

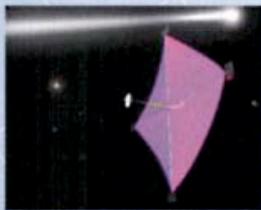
In-Space Transportation



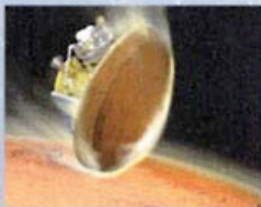
Enabling New Scientific



Solar Electric Propulsion



Solar and Plasma Sails



Planetary Aeroassist



Nuclear Electric Propulsion



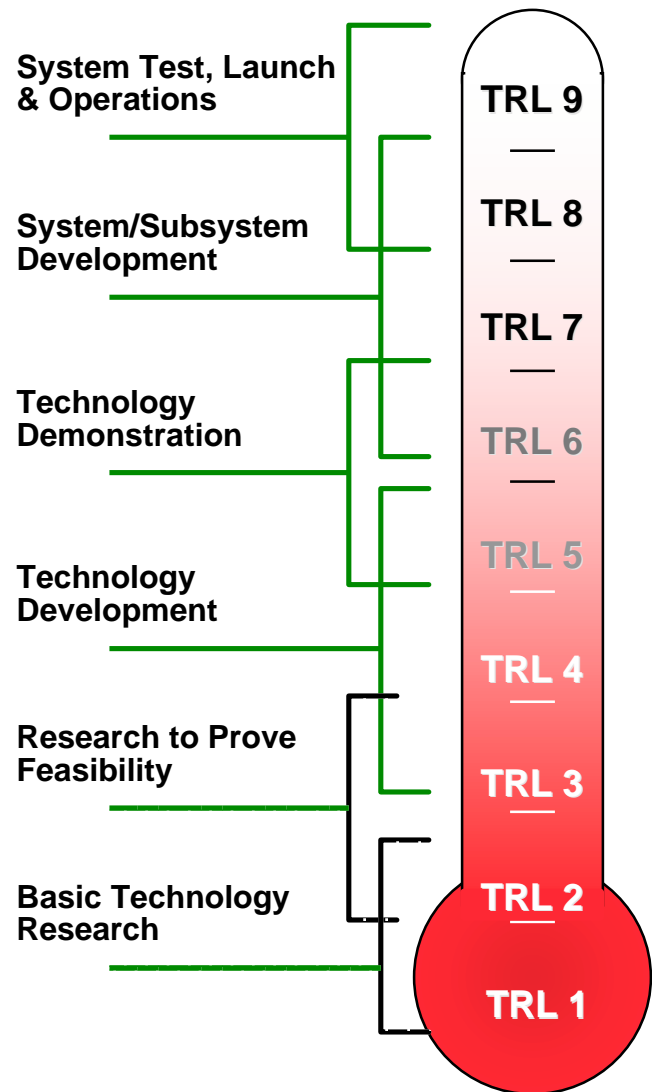
Chemical Propulsion



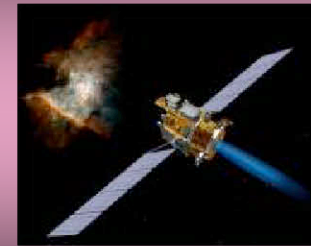
Tethers



In-Space Propulsion Program Will Advance Mid-TRL Technologies to Support NASA Mission Applications



NASA Implementation: (Deep Space One Ion Engine Example)



In-Space Propulsion Technologies

Aeroassist



Adv. Electric Propulsion



Solar Thermal



Adv. Chemical



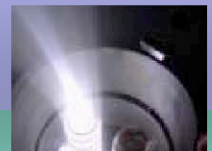
Tethers



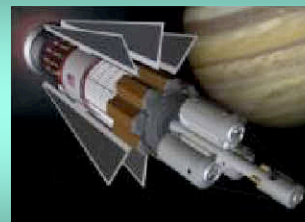
Solar Sails



Plasma Sails



Low-TRL Technologies For the Future



External Pulsed Plasma



Fusion & Antimatter



Beamed Energy

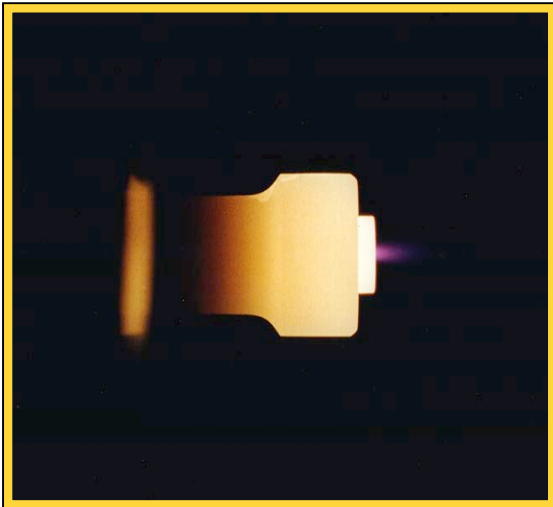
Electric Propulsion Overview

Three Classes of Concepts



Electrothermal:

Gas heated via resistance element or discharge and expanded through nozzle



Examples -
Arcjets
Resistojets
Microwave

Electrostatic:

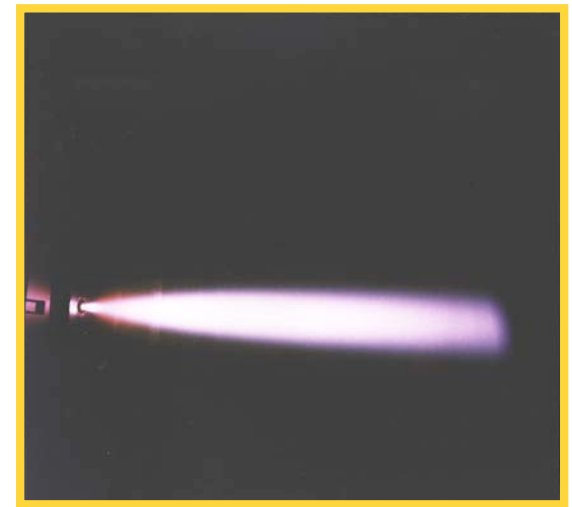
Ions created and accelerated in an electrostatic field



Examples -
Ion Engines
Hall Accelerators

Electromagnetic:

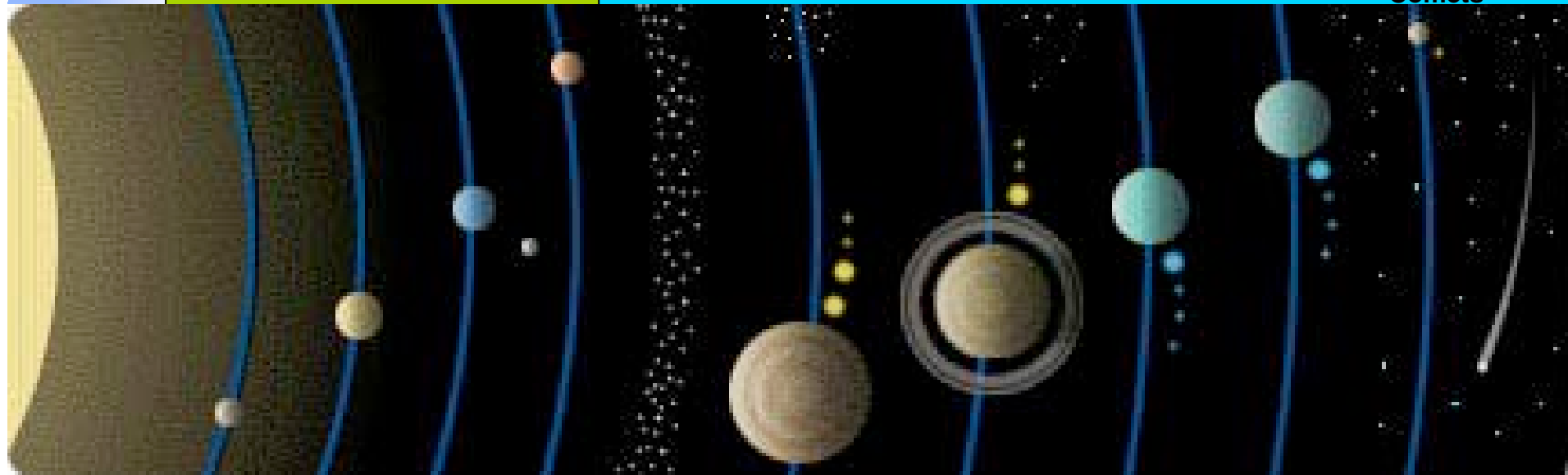
Plasma accelerated via interaction of current and magnetic field



Examples -
Pulsed Plasma
MPD/LFA
Pulsed Inductive



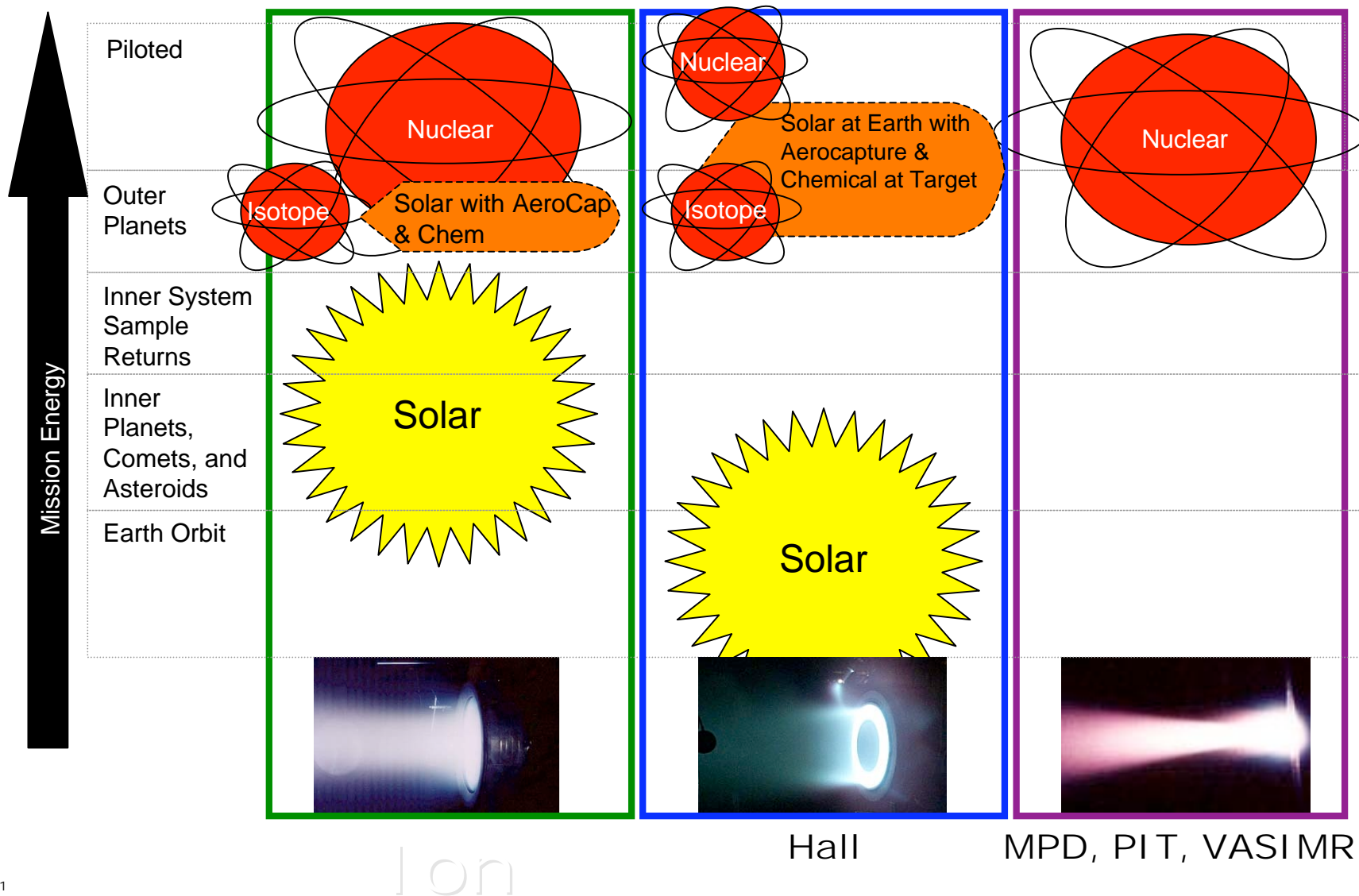
Match the Power System to the Destination

		Main Asteroid Belt	Trojan Asteroids	Centaur Minor Planets	Trans-Neptunian Objects	Kuiper Belt Objects / Comets
						
	Inner Planets	Jupiter and Moons	Saturn and Moons	Uranus and Moons	Neptune and Moons	Pluto/Charon
	Solar Electric Confined to Inner Solar System <ul style="list-style-type: none">– Also limited reach to large outer planetary bodies with aerocapture (Jupiter, Saturn, Uranus, Neptune only)	Radioisotope Electric for New Frontiers Class Outer Solar System Missions <ul style="list-style-type: none">–Targets with low Mass– 500 W Class RTG– <50 kg payload–Delta II Launchers			Nuclear Electric for Large Flagship Missions to Outer Planets <ul style="list-style-type: none">–Large Targets–100 kW Class Reactor–>500 kg Payloads–Delta IV Launch Vehicles	
RTG for Surface Lander						

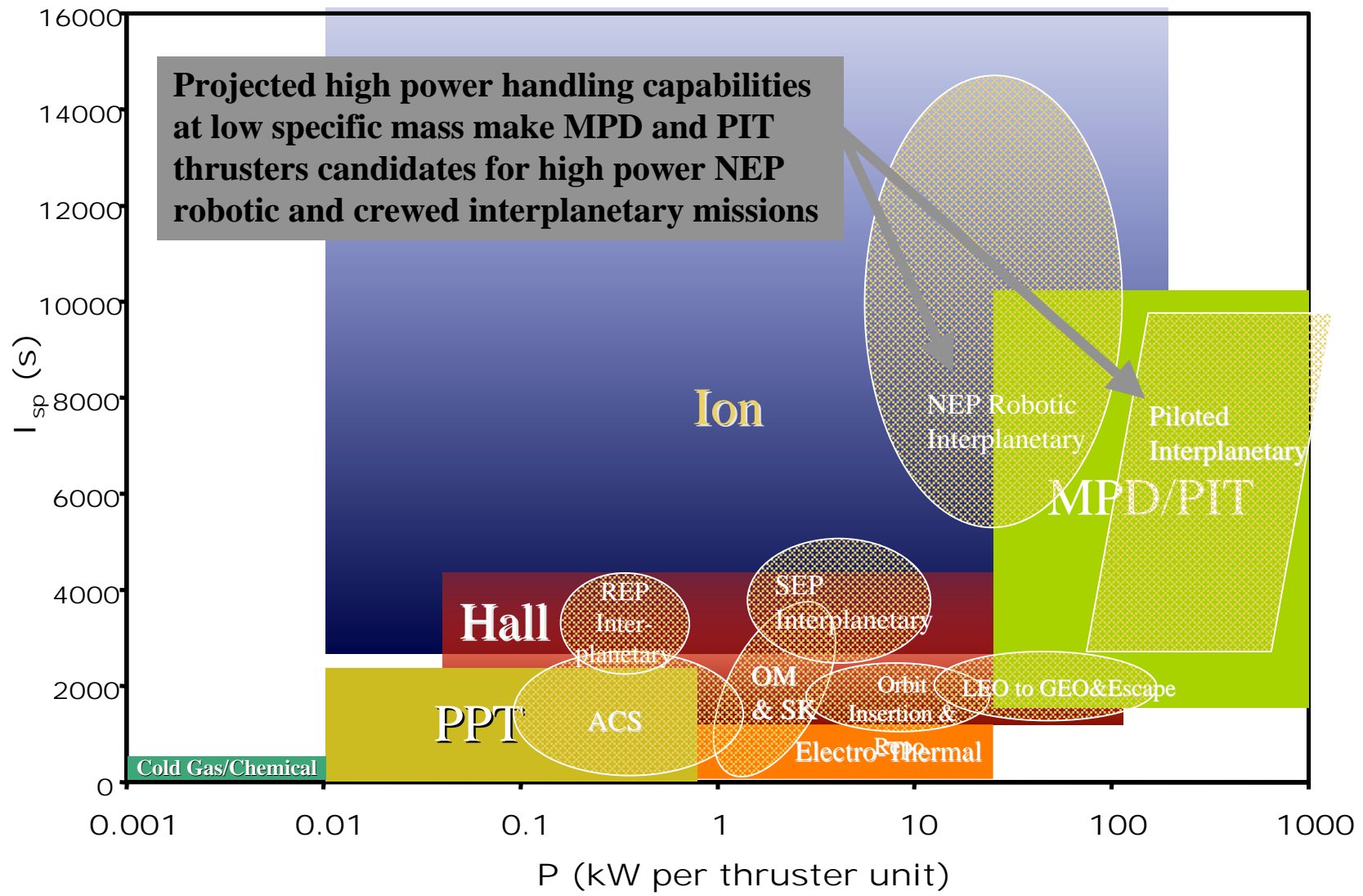
RLS0011

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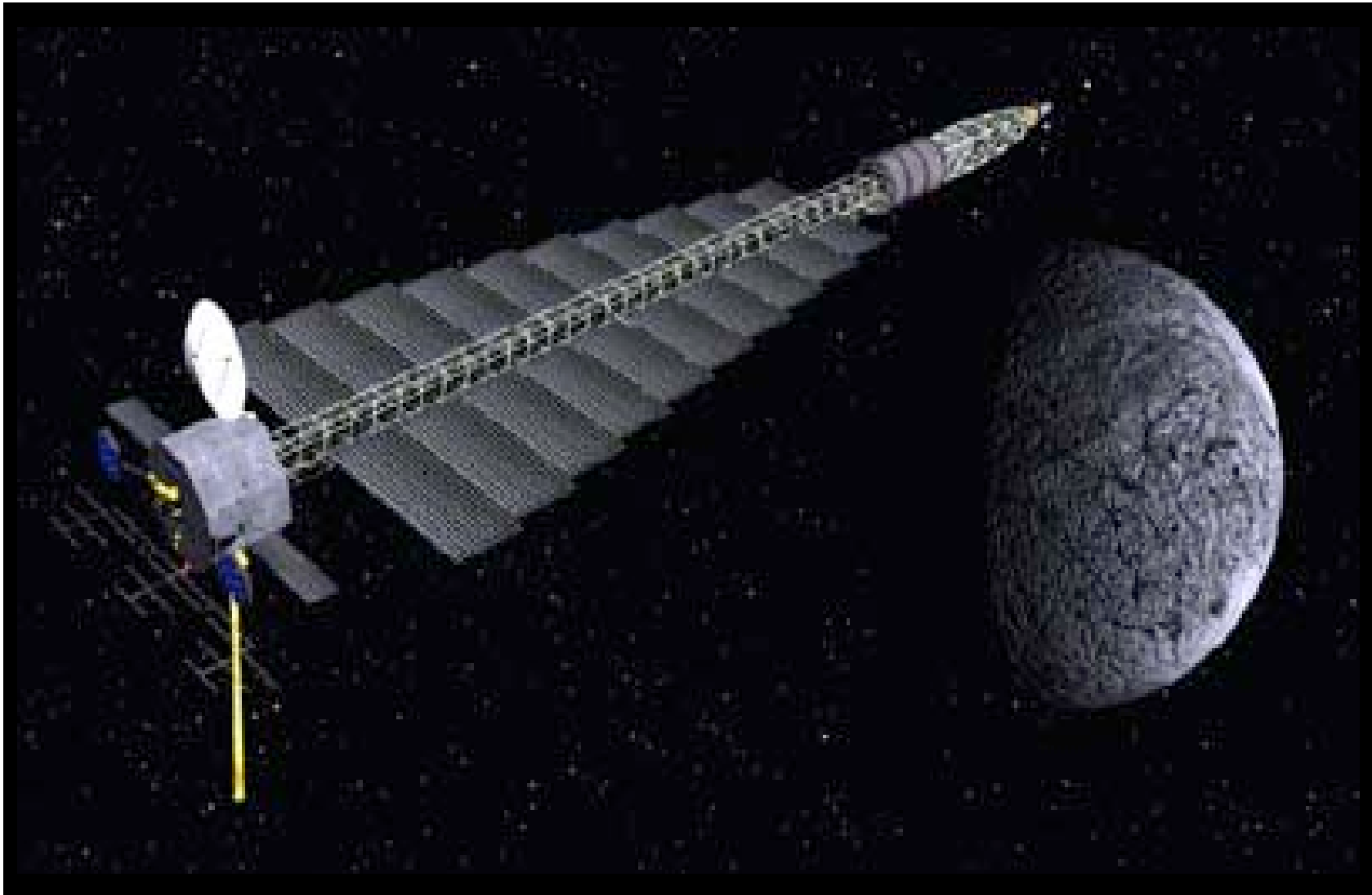
Electric Propulsion and Power Source for Space Missions



Electric Propulsion Performance

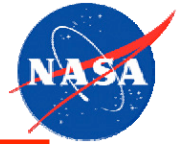


Project Prometheus



"Jupiter Icy Moons Orbiter"

Established Nuclear Energy Sources: Fission



= 50 x



**Fissioning 12 fl oz (341 ml) of Uranium
yields 50 times the energy contained in a
Shuttle External Tank
Energy Density: 82 billion joules per gram**

- **Overcomes limitations of other candidate power sources**
 - Chemical: already near theoretical performance limits
 - Radioisotopes: versatile and long-lived, but low power density and limited Pu-238 supply
 - Natural sources (e.g., solar, EM tethers): highly dependent on location w/respect to sun or planet
 - Advanced concepts (e.g., beamed energy, fusion): too immature, may not work, and/or require substantial in-space infrastructure and investment
- **Greatly extends capability, sophistication and reach of future science missions**
 - Enables use of high-performance electric propulsion beyond inner solar system
 - Provides long-duration, power-rich environments for sophisticated scientific investigations, high-data rate communications and complex spacecraft operations
- **Improves safety, capability and performance of future human planetary missions**
 - Power-rich spacecraft and surface operations
 - Rapid transportation to reduce extended exposure to solar/cosmic radiation and zero-g

Mission Objectives



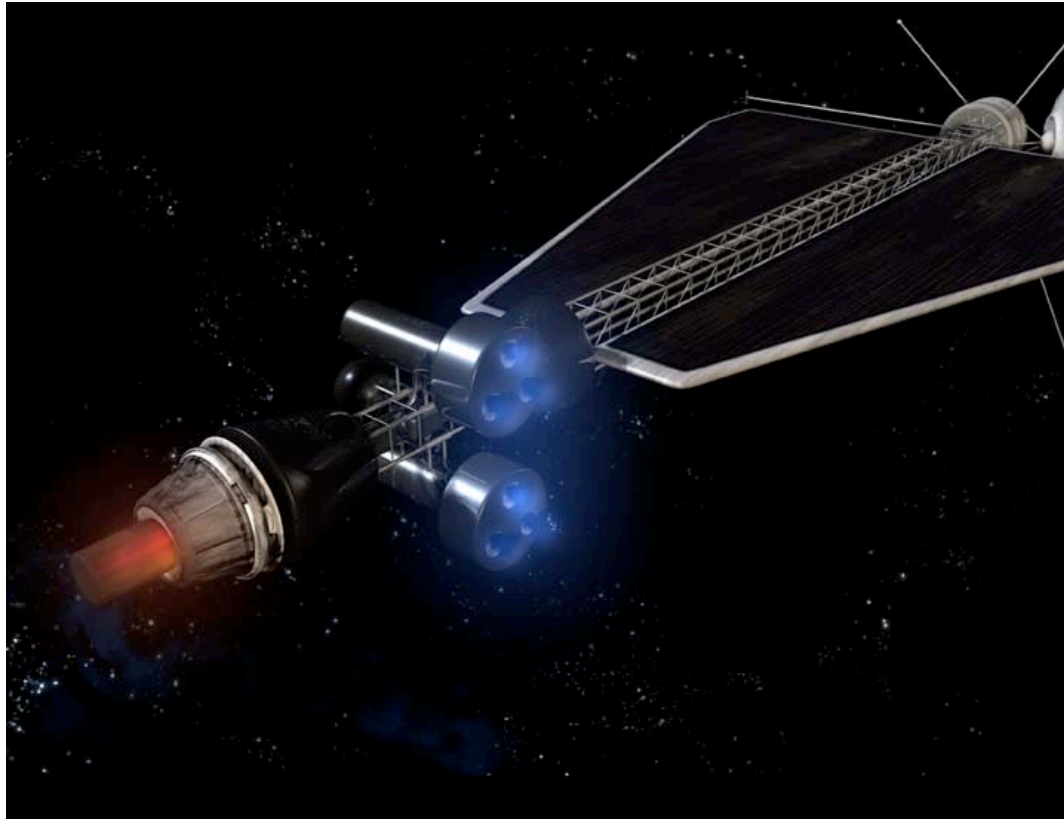
- This mission responds to the National Academy of Sciences' recommendation that a Europa orbiter mission be the number one priority for a flagship mission in Solar System exploration
- JIMO will search for evidence of global subsurface oceans on Jupiter's three icy moons: Europa, Ganymede, and Callisto.
- JIMO will be the first flight mission to use nuclear power and propulsion technologies.
- This mission will set the stage for the next phase of exploring Jupiter and will open the rest of the outer Solar System to detailed exploration.



Nuclear Electric Propulsion



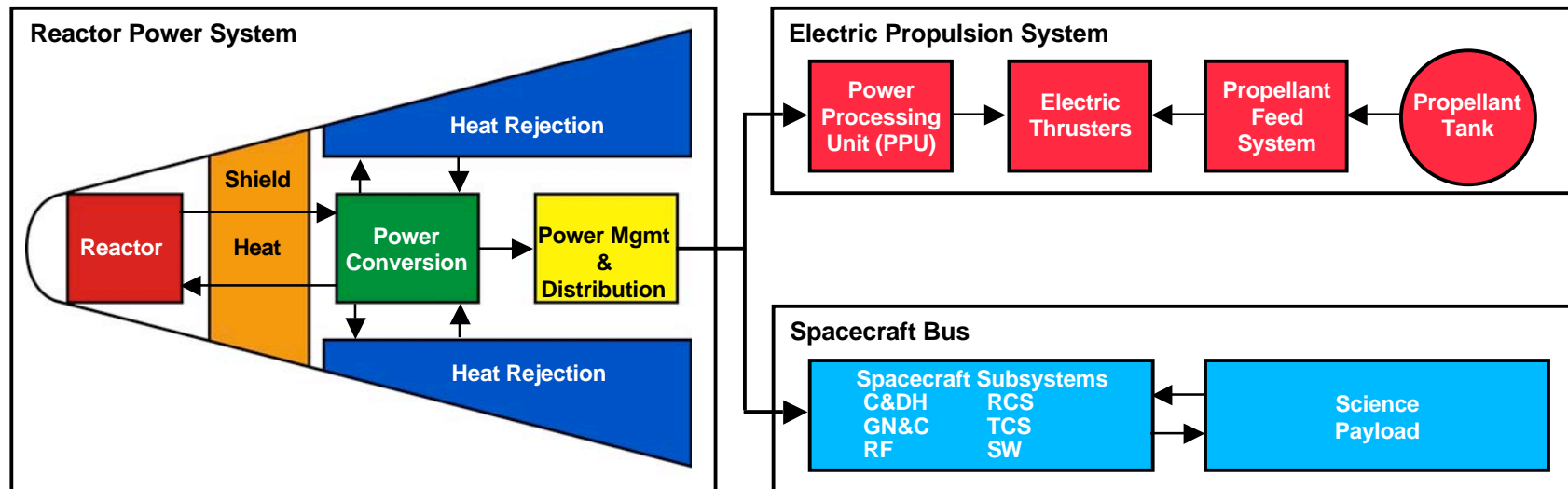
Nuclear Systems Initiative; Revolutionizing Space Exploration



***Broad Set of Concept
Options with Common
Technologies***

- **Faster Missions into Deep Space**
- **Power-rich Spacecraft for Sophisticated Investigations**
- **Ambitious Missions involving Multiple Planetary Destinations**
- **High-data Rate Communication**
- **Civil and Military Power Spinoffs**

Fission Electric Power & Propulsion System Diagram & Representative Technology Options



Reactor

Heat pipe cooled
Liquid metal cooled
Gas cooled

Power Conversion

Thermoelectric
Segmented thermoelectric
Stirling
Brayton
Thermo photovoltaic

Electric Propulsion

Ion thruster
Hall thruster
MPD, PIT

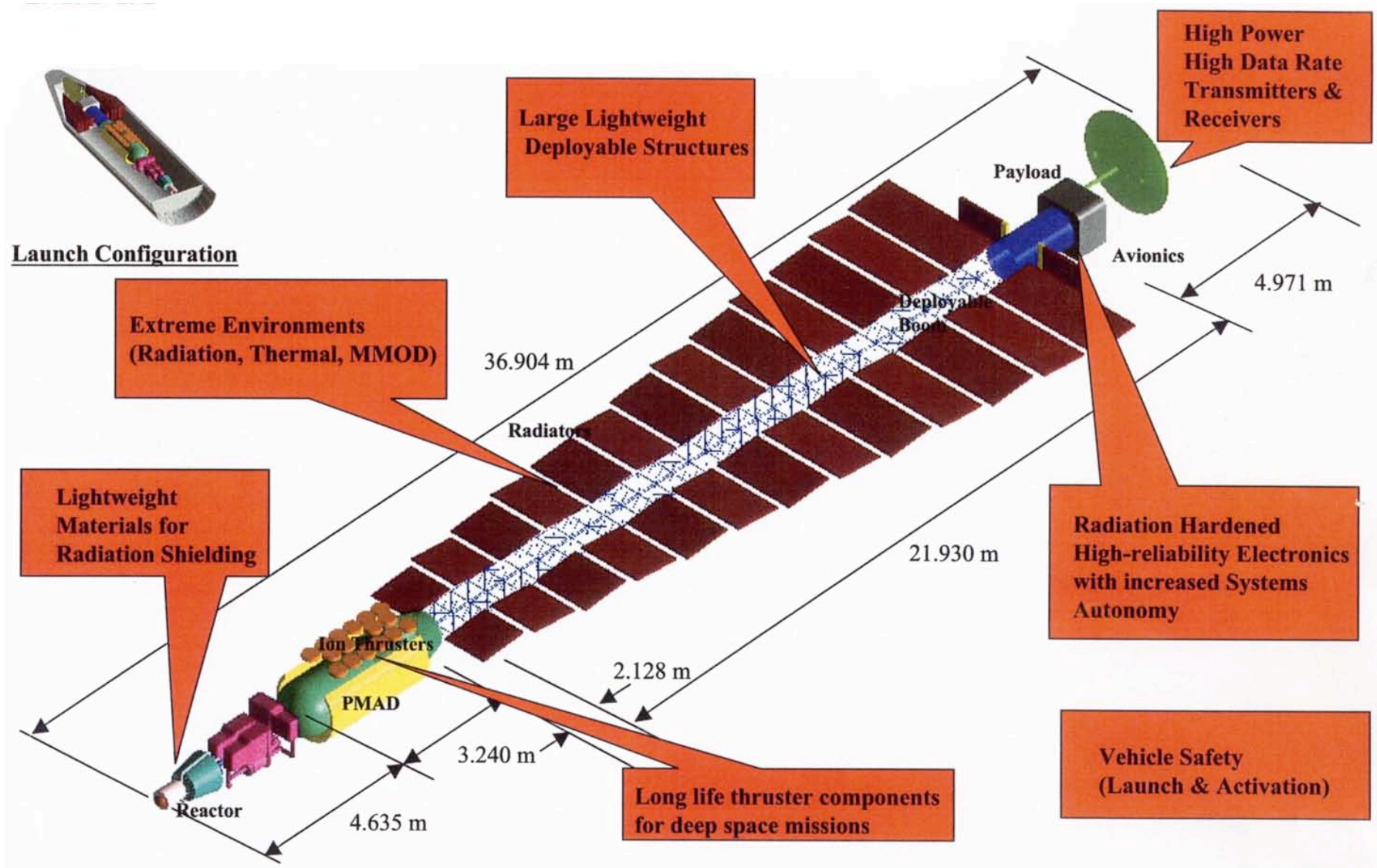
Heat Rejection

2-phase loops (capillary pumped loop, loop heat pipes)
Heat pipes
Pumped loops

Power Management and Distribution

Depends upon power conversion:
AC
DC
Low/high input voltage

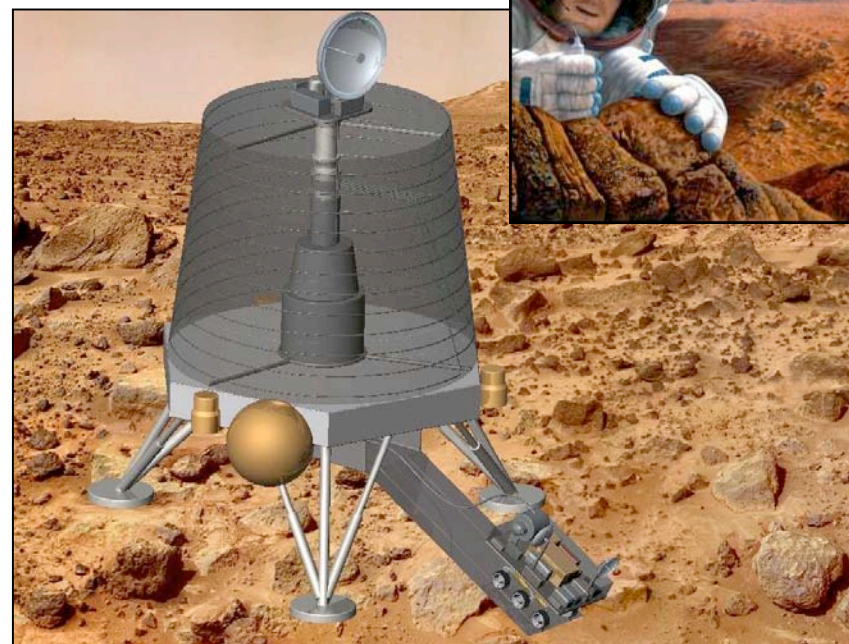
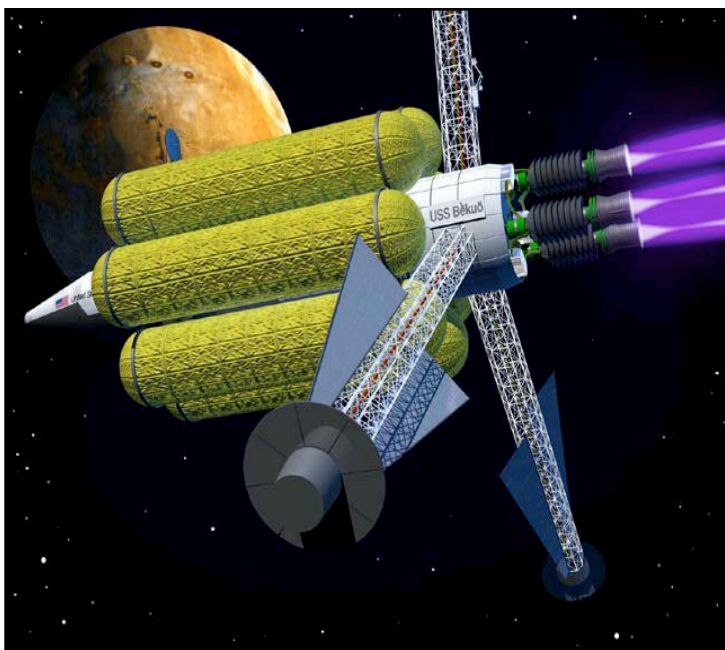
Technical Challenges Required For NEP Systems Development



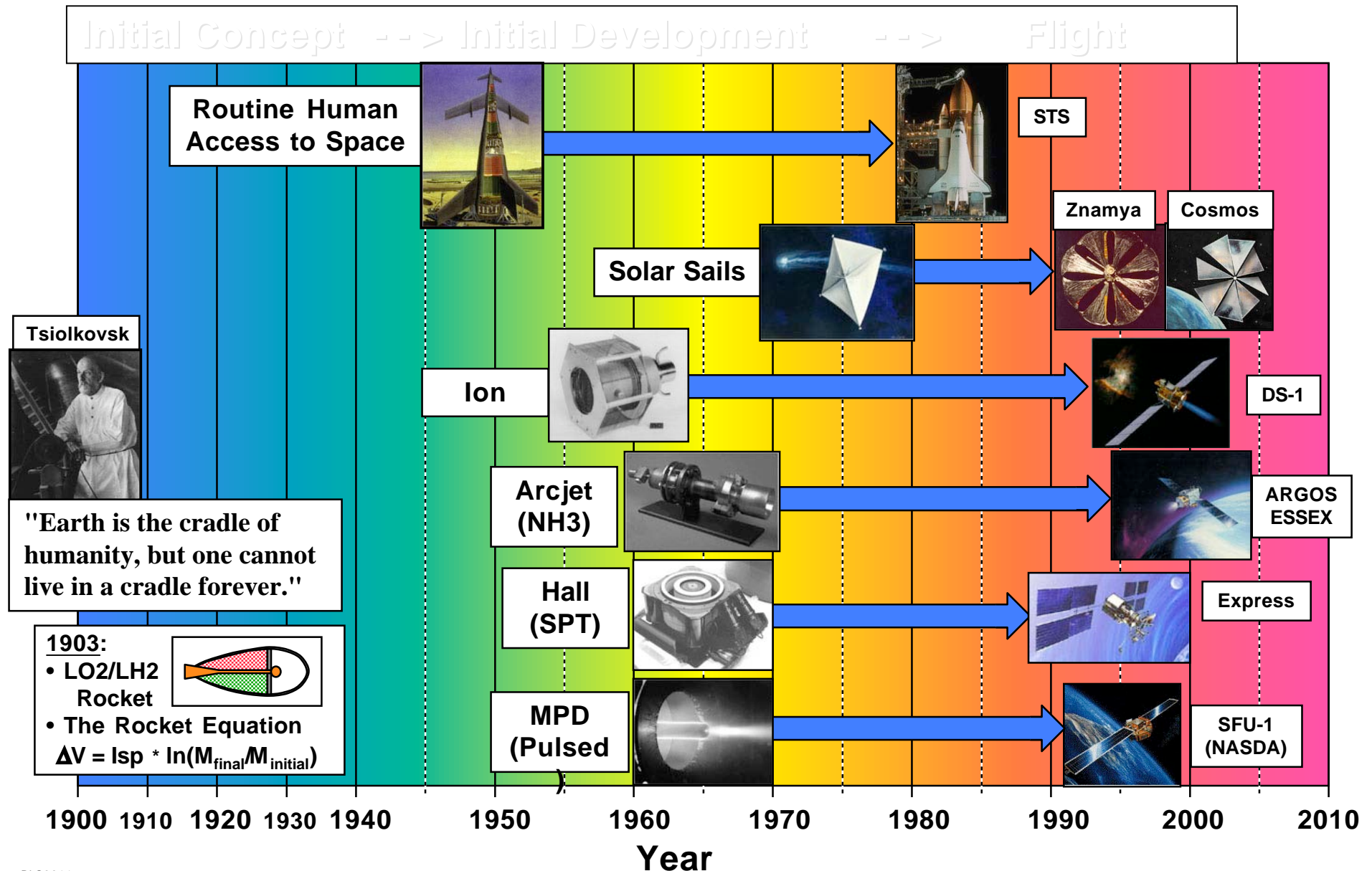
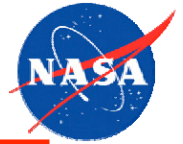
Potential Support to Human Space Exploration



- Nuclear power and propulsion are key enablers of expanded human exploration
 - Enables human exploration beyond earth orbit
 - Provides high power for human protection against charged solar particles
 - Provides abundant power at destination
 - Enables complex, long duration missions
- Nuclear surface power is essential for extended reconnaissance of the Mars surface
 - Long-range surface and sub-surface exploration
 - Human habitat and life support
 - *In-situ* manufacturing of consumables
 - *In-situ* propellant production



Development of Low-TRL Propulsion Technologies Can Take Decades



Propulsion Research

Unlocking the Potential of A Broad Spectrum of Revolutionary Concepts

NASA

*Fission & Fusion
Propulsion*

*Antimatter
Propulsion*

*Breakthrough
Physics*

*Advanced Chemical
Propulsion*

*Electro-magnetic
Propulsion*

Rocket Engine Prototype (REP) Project Overview

◆ Objectives

- Provide risk mitigation for large class, Oxygen Rich Stage Combustion Engine (ORSC)
- Design and Test a high-fidelity prototype engine
- Validate existing analytical tools
- Develop and validate new analytical tools as required to develop the flight ORSC engine system

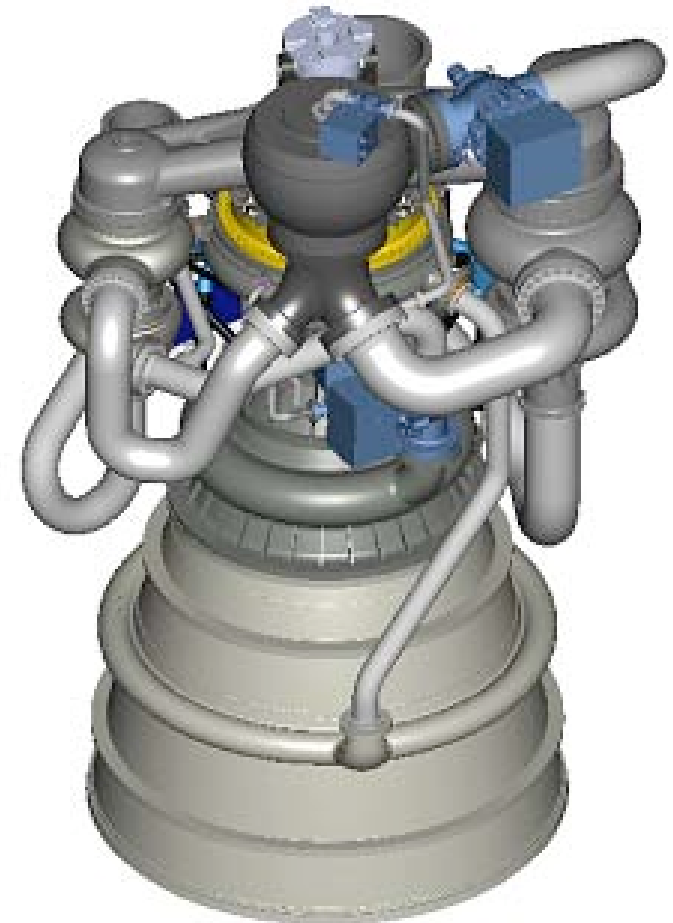
◆ Success Criteria

- ORSC Engine System @ TRL 6 (demonstration in relevant environment)

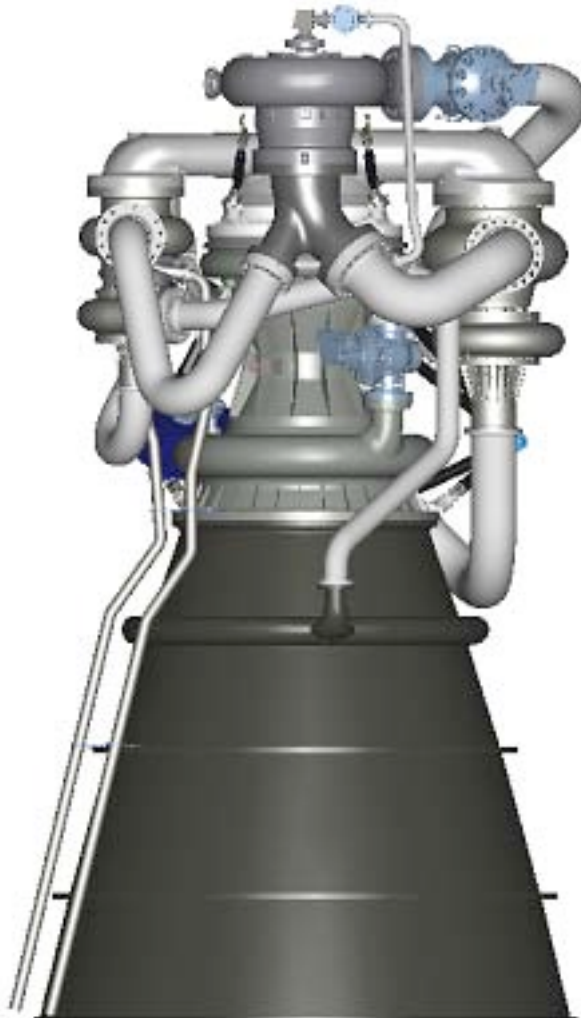
◆ Goals

- Improved Safety
- Reduced Cost
- Improved Operability and Responsiveness

◆ Current Activity limited to Prototype Engine Design and Technology Development



ORSC Prototype Engine Characteristics

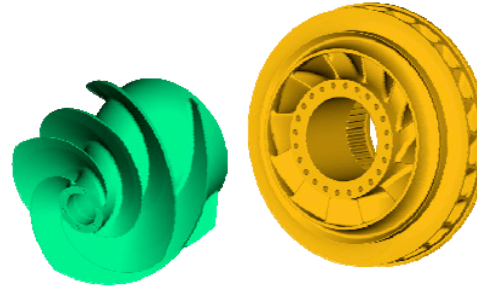


	<u>Prototype</u>	<u>Reference</u>
Thrust		
• Sea Level klb.	1064	1049
• Vacuum klb.	1130	1160
Reliability		
• Failures Per Million Missions traceable		18
Operability		
• Shift turn time	8	8
Specific Impulse		
• Sea level sec.	305	301
• Vacuum sec.	324	335
Weight		
• Dry lbm.	17,922	14,956
Life		
• Missions	100	100
Dimensions		
• Length in.	147	184
• Diameter in.	108	108
• Area Ratio	20:1	36:1

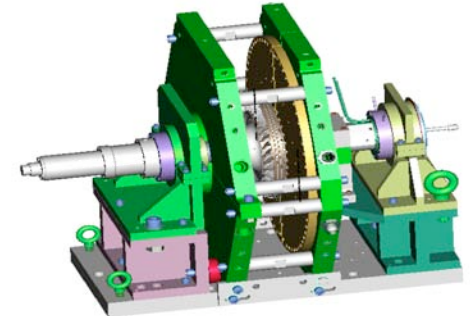
Rocket Engine Prototype Project Overview

◆ Deliverables

- Oxygen Compatible Materials
- Manufacturing Technology Demonstrations
- Turbopump Inducer Waterflow Test
- Turbine Damping “Whirligig” Test
- Single Element Preburner and Main Injector Test
- 40K Multi-Element Preburner and MI
- Full-Scale “Battleship” Preburner
- Prototype Preburner Test Article
- Full-Scale Prototype TCA
- Turbopump Hot-Fire Test Article
- Prototype Engine
- Validated Analytical Models



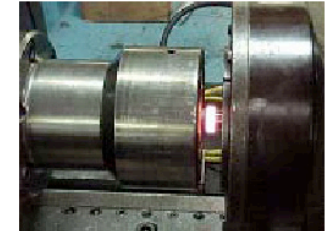
Inducer & Impeller Test Articles



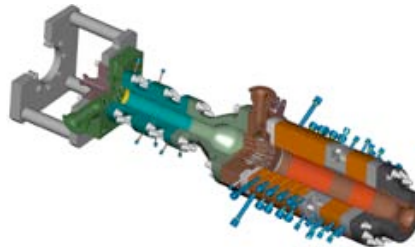
Whirligig Test Article



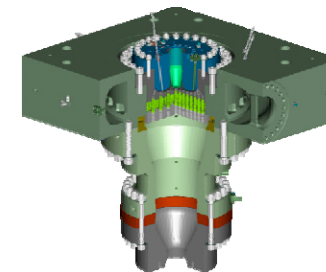
Single Element Test Rig



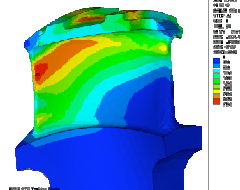
Inertial Weld Sample



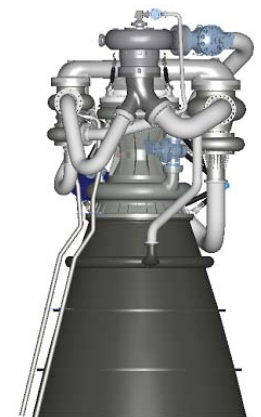
40K Test Rig



Battleship Preburner



Turbine Blade Analytical Model



Prototype Engine

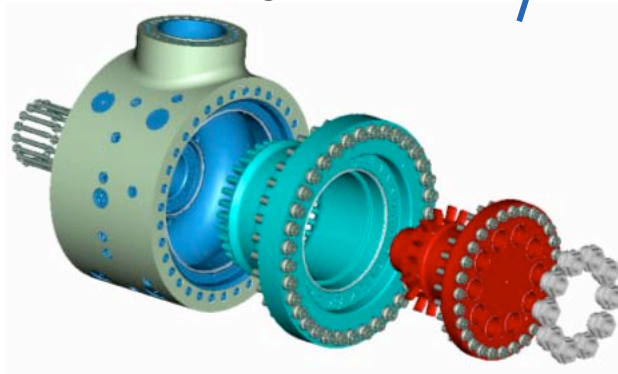
On Current Contract

◆ Full-Scale Preburner

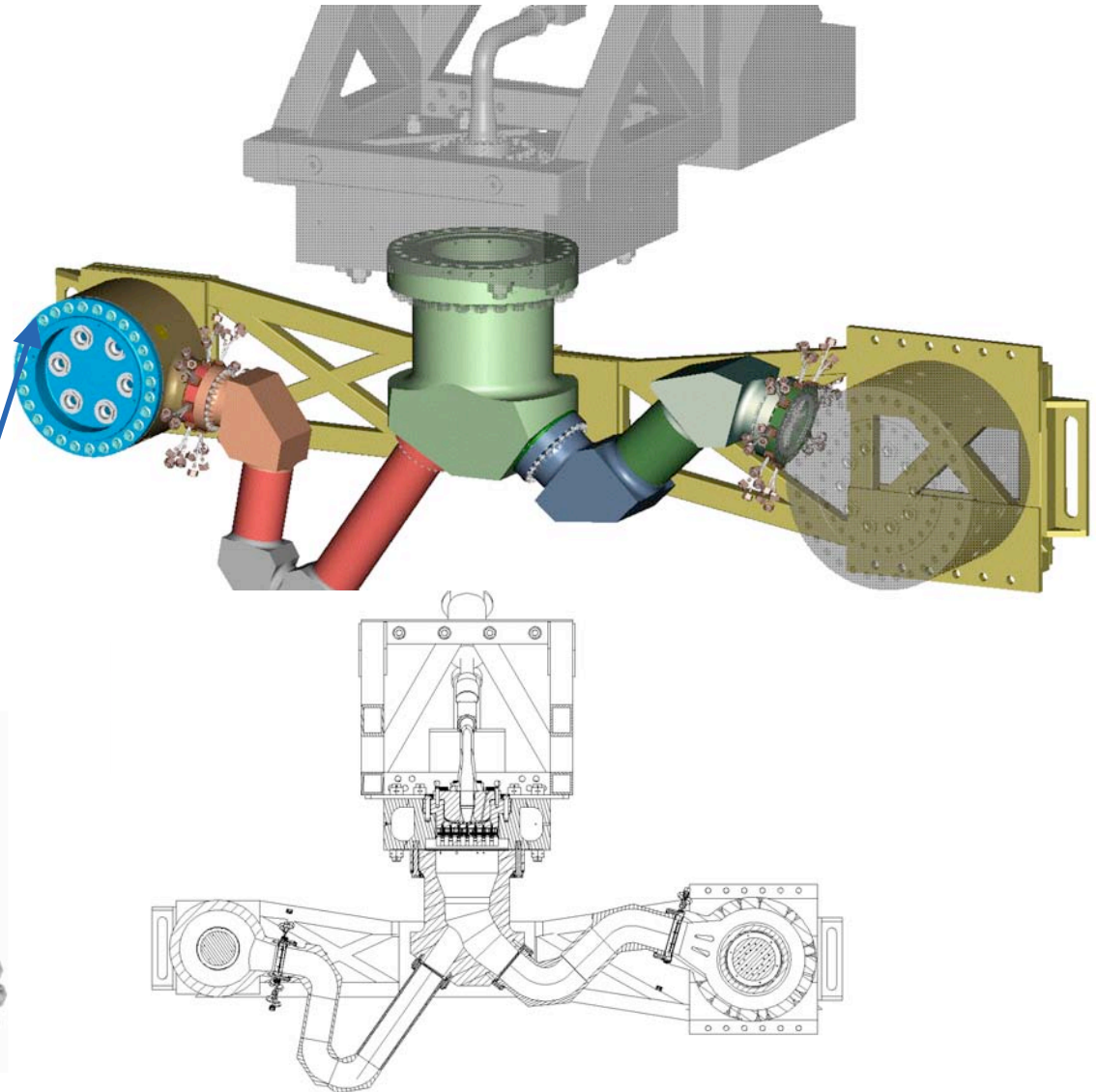
- High fidelity simulation of internal flow geometry
- Injectors, Chamber, Splitter Ducts, and Turbine Simulators

◆ Objectives

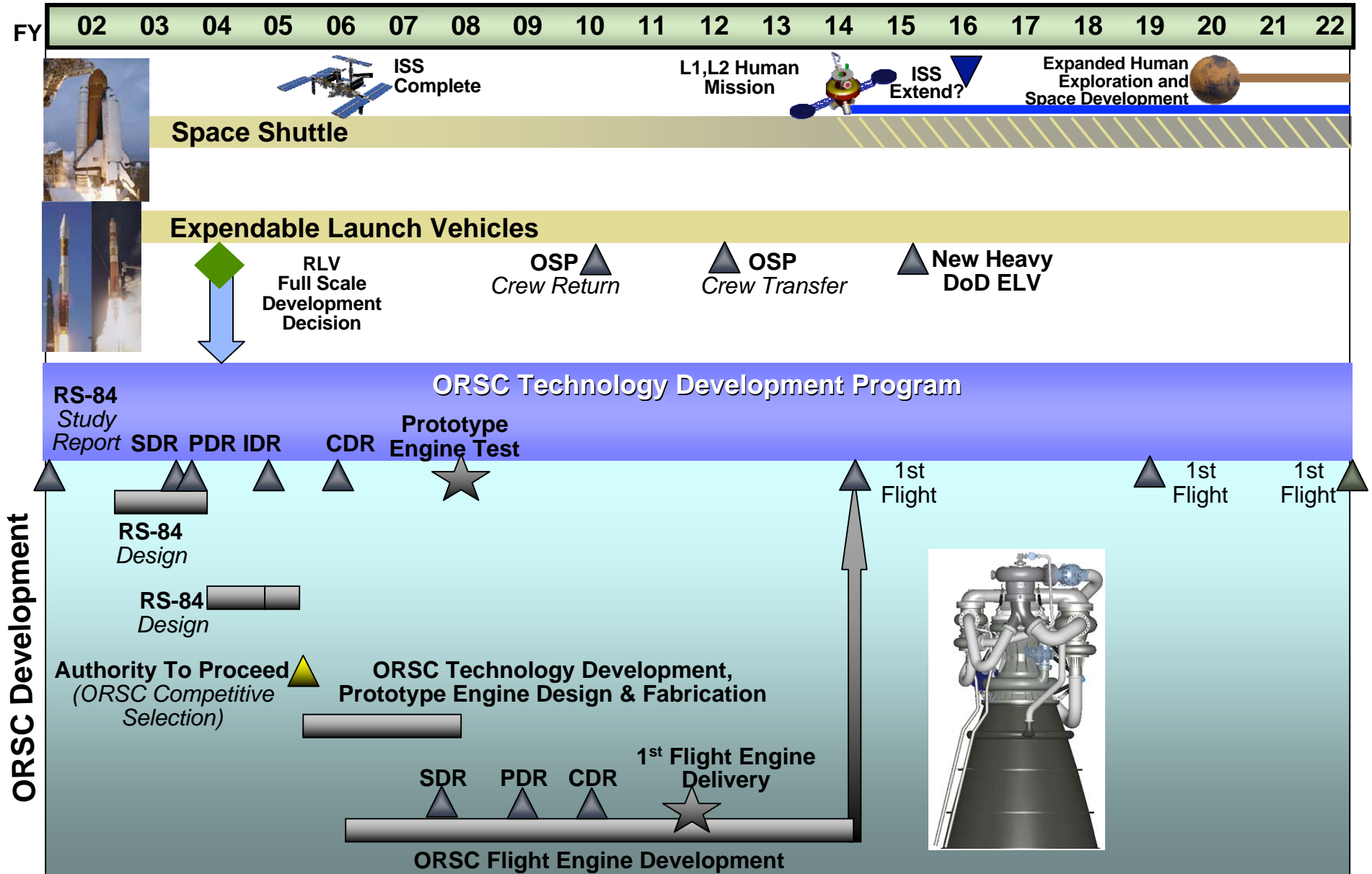
- Stability demonstration
- Flow uniformity at turbine inlets
- Materials usage



Turbine Simulator

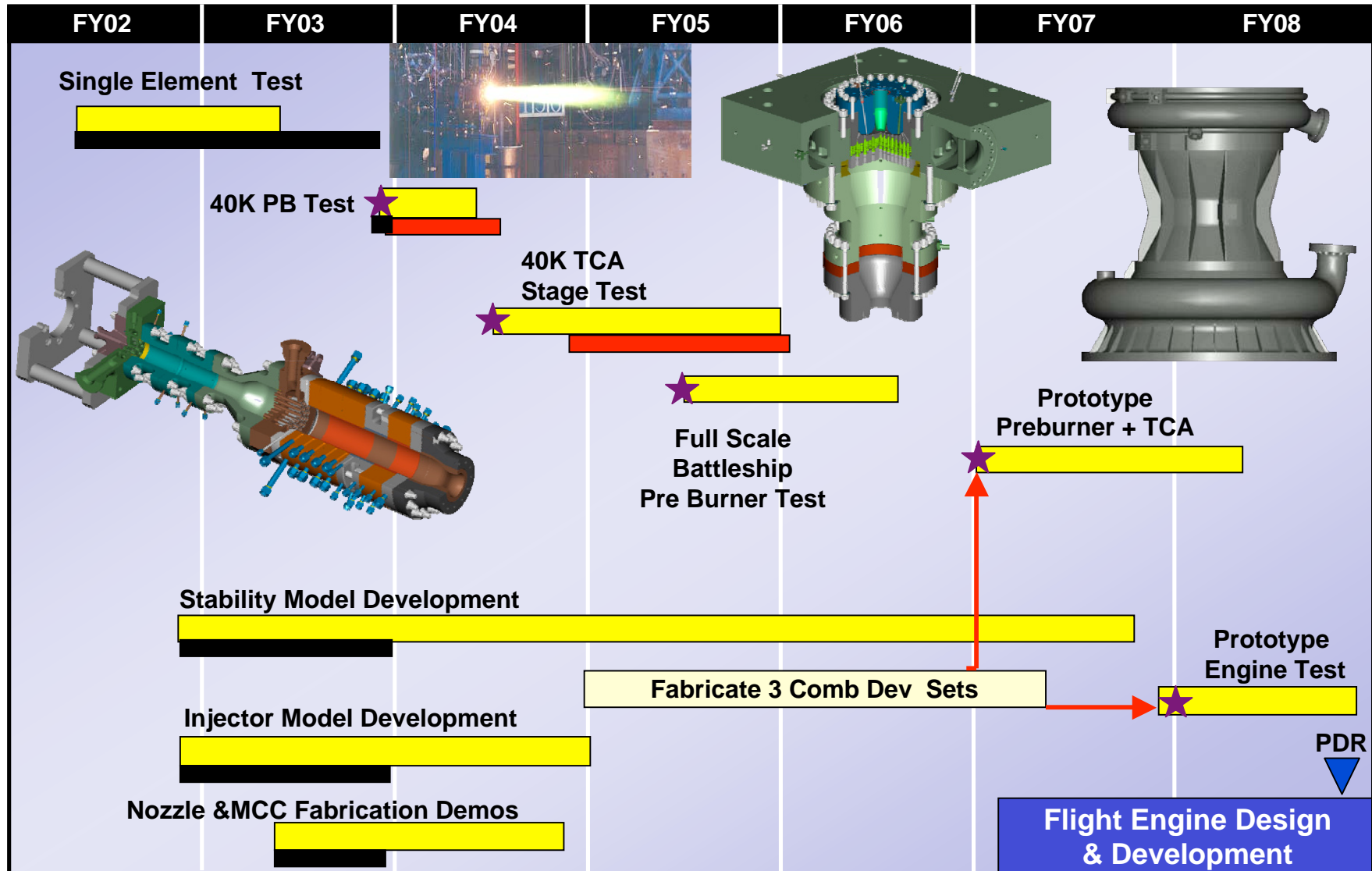


NGLT & REP ORSC Future Space Launch Roadmap



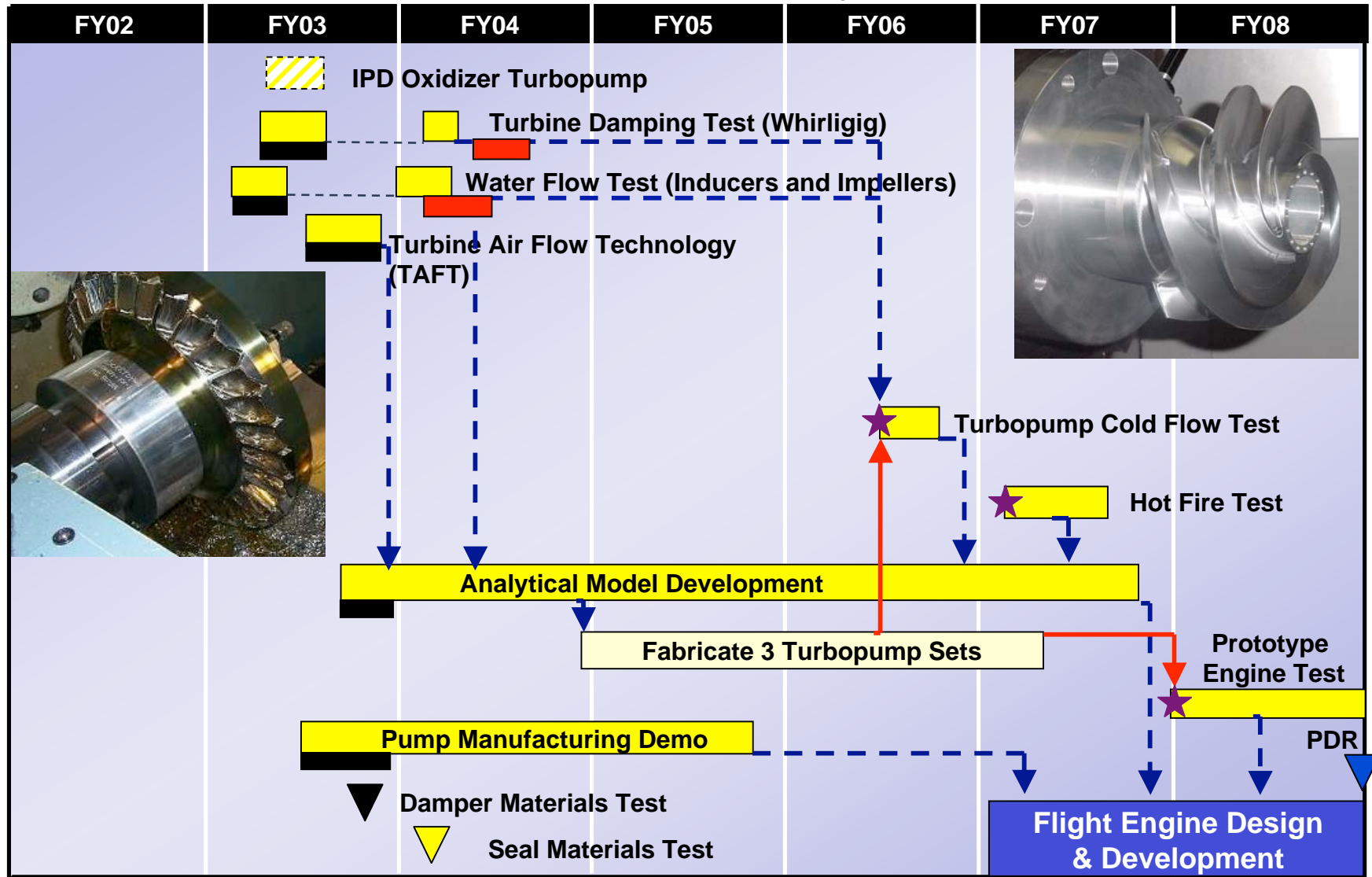
REP ORSC Combustion Devices Roadmap

Combustion Devices



REP ORSC Turbomachinery Roadmap

Turbomachinery



★ Program Milestone